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Evaluation of the Potential for Biotechnology in the Canadian Mining Industry

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A report prepared by

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EVALUATION OF THE POTENTIAL FOR BIOTECHNOLOGY IN THE CANADIAN MINING INDUSTRY

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TABLE OF CONTENTS

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SUMMARY

The National Biotechnology Advisory Committee (NBAC) advises the Minister of Industry Canada on issues relevant to various industrial sectors. On behalf of the Committee, a study was commissioned for the mineral sector, supported by Industry Canada and CANMET, Natural Resources Canada, to provide senior executives in industry and policy makers an analysis of the current status and future potential of biotechnology for metal recovery and environmental control.

This report compiles biotechnology processes in production and at various stages of development classified by commodity. Summaries are provided for base metals and uranium leaching; gold and silver processes; environmental applications; fossil fuels; and industrial minerals. For each sector, a summary provides the status of the technologies indicating whether the technology is commercial, near commercial, demonstrated at pilot scale, demonstrated at laboratory scale, or at the conceptual stage. Technologies within each sector are briefly discussed and key references provided. For commercial and near-commercial technologies used world wide and in Canada, details are provided on process principles, applications, limitations, required developments, patents, and other factors. The review indicates a number of technologies which could find new or additional applications in Canada.

An economic analysis of selected technologies shows that several biotechnology processes are economic given a specific context (grade, price, location...) and have a preferred domain of application. There are relatively small incremental differences between co-existing processes, weighted or adjusted by their associated risk factor. A strong trade-off exists between conventional processes and biotechnology processes in relation to environmental friendliness. The balance of costs, that currently favour biotechnology in specific cases only, are frequently tipped in the favour of biotechnology when a greater emphasis is put on environmental factors. Under such conditions, cleaner effluents would be achievable in many cases at lower cost with biotechnology processes than with conventional processes.

A compilation of mineral reserves in Canada on a Provincial basis has been carried out. The potential of reserve growth through changes in cut-off grade is evaluated using grade distribution versus cumulative tonnage curves for selected metals. Separately reported are the tonnages of mine waste and mill tailings that could be the source of metal extraction. It was expected that the most affected by the introduction of biotechnology would be from identified deposits not committed to be mined. However, the analysis showed that the impact of biotechnology on such reserves is modest. None of the new technologies evaluated would permit the mining of large tonnages of lower grade deposits. Refractory gold deposits and the use of wastes and tailings as a source of values could make important reserve increases. Companies should be given credit for exploiting wastes and tailings due to the significant environmental benefits that would accrue. A detailed inventory of wastes and tailings in Canada is recommended.

Regulations affecting the use of biotechnology and biotechnological products in Canada are reviewed. The impact of impending regulations on the Canadian mining industry is discussed and guidelines for potential users of processes or importers/manufacturers of products are given.

A compilation of the expenditures on research and development in biotechnology in mining shows that expenditures are principally made by Energy Mines and Resources (now Natural Resources Canada) and specifically CANMET. Expenditures for the period 1981- 1995 are given. Included are internal expenditures and contracts awarded by CANMET for external research. Significant funding of projects by industry and at universities and research organizations could not be quantified to provide a meaningful analysis. Public investment should be directed towards projects which have an environmental benefit.

The Canadian mineral sector has been slower to embrace biotechnology compared to those of other countries. Barriers to the application of biotechnology in the Canadian mining industry are discussed with particular reference to risk. The perceived risk for biotechnology has been high but as commercial experience and operating data accumulate, technologies are gaining greater acceptance. Barriers will come down for specific technologies and biotechnology will achieve greater acceptance as the market evaluates if the risk is acceptable for the expected benefit.

RÉSUMÉ

Le comité consultatif national de la biotechnologie (CCNB) conseille le ministre d'Industrie Canada sur des questions pertinentes à différents secteurs industriels. Ce comité a commandé une étude sur le secteur minéral laquelle est financée par Industrie Canada et Ressources Naturelles Canada, CANMET. L'étude apporte au personnel de direction et aux législateurs une analyse du statut actuel et du potentiel futur de la biotechnologie pour la récupération des métaux et le contrôle de l'environnement.

Le rapport fait l'inventaire des procédés biotechnologiques classés par produit, en usage et à différents stades de développement. Des sommaires sont donnés pour les métaux de base et le lexiviage de l'uranium, les procédés pour l'or et l'argent, les applications environnementales et les combustibles fossils. Pour chaque secteur, un résumé présente le statut de la technologie indiquant si elle est commerciale, quasi commerciale, démontrée à l'échelle du project pilote ou bien à l'étape conceptuelle. Les technologies sont brièvement présentées ainsi que leurs principales références bibliographiques. Pour les technologies commerciales et quasi commerciales utilisées dans le monde et au Canada, des détails supplémentaires sont fournis tel que les principes du procédé, les applications, les limites, les développements requis, les brevêts et divers autres facteurs. La revue des technologies indique qu'au Canada des applications nouvelles ou additionnelles seraient possible.

L'analyse économique d'une sélection de technologies montre que plusieurs procédés biotechnologiques sont économiques dans un contexte donné (teneur, prix, localisation...) et qu'ils ont aussi des domaines d'application privilégiés. La différentielle de coût est relativement minime entre les procédés co-existants une fois pondéré ou ajusté par leur facteur de risque. Le changement des procédés traditionnels par ceux biotechnologiques résulterait en une meilleure disposition envers l'environnement. De même, lorsqu'une plus grande emphase est placée sur les facteurs environmentaux, le résultat de la

comparaison des coûts se déplace en faveur des procédés biotechnologiques. Sinon, ces procédés ne sont favorisés que dans des cas spécifiques. Des effluents plus propres, si exigés, seraient réalisable à bien meilleur coût avec des procédés biotechnologiques plutôt qu'avec des procédés traditionnels dans plusieurs cas. L'investissement de fonds publiques devraient n'être dirigés que vers les projets produisant un bienfait environnemental.

Les réserves minérales du Canada ont été compilées sur une base provinciale. Le potentiel de croissance des réserves, par le changement de la teneur de coupure pour une sélection de métaux, est illustré par des courbes de la distibution des teneurs en fonction du tonnage cumulé des gisements. Les tonnages de résidus miniers et de rejets de concentrateurs qui pourraient être source d'extraction de métaux sont rapportés séparément. Il était anticipé que les réserves qui seraient les plus affectées par l'introduction des biotechnologies seraient celles provenant de gisements découverts mais non commis à l'exploitation. Toutefois, l'analyse demontre que l'impact des biotechnologies sur ces réserves est modeste. Aucune des nouvelles technologies étudiées pourraient exploiter à grand tonnage des gisements de basse teneur. Les gisements d'or réfractaires ainsi que l'utilisation des résidus miniers et des rejets de concentrateurs comme matériel source pourraient faire des augmentations de réserves significatives. Les compagnies qui exploiteraient les résidus miniers et les rejets de concentrateur devraient recevoir des crédits à cause des bienfaits environmentaux qui en résulteraient. Un inventaire détaillé des résidus miniers et des rejets de concentrateurs est recommandé.

Les règlements affectant l'usage des biotechnologies et des produits biotechnologiques au Canada sont examinés. L'impact de l'entrave de ces réglements sur l'industrie minière canadienne est discuté et les directives à l'intention des utilisateurs potentiels de procédés ou d'importateurs/manufacturiers de produits sont présentées.

Une compilation des déboursés en recherche et développement en biotechnologies dans le secteur minier montre qu'ils sont principalement réalisés par le ministère d'Energie, mines et ressources (maintenant Ressources Naturelles Canada) et plus spécifiquement CANMET. Les déboursés pour la période 1981-1995 sont donnés. Il y est inclus les déboursés internes de CANMET et les contrats accordés à des chercheurs externes. Les soutiens importants à des projets par l'industrie, dans les universités et dans les organismes de recherches n'ont pu être suffisament quantifié pour permettre une analyse significative.

Le secteur mineral canadien a été plus lent à adopter la biotechnologie en comparaison avec ceux de d'autres pays. Les barrières, dans l'industrie minière canadienne, relatives à l'application des biotechnologies sont discutées en fonction de la notion de risque. Le risque perçu associé aux biotechnologies est élevé mais suite à des expériences commerciales et à l'accumulation de données d'opération, ces technologies trouvent maintenant plus grande créance. Pour des technologies spécifiques, les barrières disparaîtront et la biotechnologie aura meilleur accueil lorsque le marché jugera le risque acceptable pour les bénéfices anticipés.

CHAPTER 1

INTRODUCTION

1.1 Objectives and Scope of the Study

This report presents the results of a study on the potential of biotechnology in the mining industry commissioned by the Mining Sector Working Group of the National Biotechnology Advisory Committee to provide the information necessary to make informed recommendations to the Minister of Industry Canada with respect to regulatory maters and federal research funding priorities for biotechnological applications. The results will also provide decision makers in the mining industry, investors, and technology policy makers an analysis of the current role and future potential of biotechnology for metal extraction, metal recovery and environmental control. Although the focus of the study is on the potential for the Canadian industry, the analysis will consider biotechnology applications, research and development worldwide.

The study was undertaken with the following principal objectives:

1. To carry out an independent study to define the potential value of biotechnology applications to increase economic mining reserves and/or reduce the environmental cost of mining in Canada.
2. To provide recommendations to prioritize research expenditures, both government and industry, and highlight relevant regulatory issues.
3. To provide a clear indication of the potential return on investment for using biotechnology in exploration, mining extraction, mineral processing, refining, waste treatment and site closure/remediation.
4. To present the potential benefits of biotechnology applications in mining to mining company executives to increase their level of awareness and confidence in biotechnology and to increase expenditures by the industry on biotechnology research, development and application.

This report provides a compilation of the data and analysis which were carried in accordance with the following tasks:

- Compilation and summary of information on successful applications of biotechnology in mining in Canada and abroad, and on technologies which are under development.
- Carrying out a cost-benefit analysis of commercial, near-commercial technologies and technologies considered to have future potential for use in the Canadian mining industry and by the Canadian industry abroad.
- Compilation and summary of information on the potential reserves that might benefit from biotechnology applications in Canada. This included an assessment of the quantities of tailings and other waste rock that could become the source of values.

- Review of current and planned regulations affecting biotechnology to determine the potential impact on the mining sector.
- Compilation of statistics on current research and development expenditures on biotechnology in the mining sector in Canada.
- Identification of barriers, both real and perceived, to the application of biotechnology in mining.
- Presentation of the findings to industry and government in a series of oral presentations.

Following this introduction, Chapter 2 provides information on technologies which are compiled and reviewed by sector and application. An economic analysis of commercial and near-commercial technologies and technologies considered to have potential application is presented in Chapter 3. The Canadian context is provided through an analysis of the potential impact of biotechnology on Canadian mineral reserves, including the potential value of tailings and other waste materials (Chapter 4) and through a review of proposed regulations which could affect applications in Canada (Chapter 5). The barriers, real and perceived, to the application of biotechnology are discussed in Chapter 6. The conclusions of the study are discussed in Chapter 7. A listing of source material on biotechnology in mining is provided in Appendix II for the benefit of those unfamiliar with this field.

The selection, classification, assessment of status, and relevance and economic pertinence, and other features of processes described herein are the responsibility of the authors. However, omissions are possible because of lack of information. These are not intentional and should be seen as reflecting negatively on a particular process or its development.

1.2 The Technology Needs of the Mining Industry

Canada is one of the major mining nations of the world, and should remain one of the leading producers and exporters based on its proven geological reserves, established industry, and projected demand (1). Its production ranks first in nickel, zinc and uranium, and third in copper and cobalt. In all, Canada ranks 1 to 10 in the world in 22 major minerals. In addition, the industry makes a significant contribution to the development and operation of mining ventures in many other countries of the world.

The mining industry in North America has undergone considerable change over the past decade. Following a booming period in the 1970's, the domestic industry has seen a decline due to a number of factors including higher energy costs, lower grade ores, increased labour demands, competitive foreign imports of raw and processed metal materials, lower cost operations in South America and elsewhere in the world, and increased environmental pressures, both public and regulatory. These factors have contributed to mine closures, reduced production, layoffs and a movement of company operations to other countries in the world. Although it can be demonstrated that today the Canadian mining industry is flourishing, it is not necessarily to the direct benefit of Canadian labour, the towns which depend on mining for their economic well-being, and the population at large through the generation of tax revenues. It is in countries such as Chile, where large tonnage, high grade copper orebodies are being found and exploited, where many of our mining companies are currently choosing to operate.

Although considerable progress continues to be made in the development of new technologies and methods for mining, mineral processing, extractive metallurgy and environmental compliance, the Canadian mining industry will need to develop and adopt even newer technologies to remain competitive at home in the future. Today, an analysis of current mineral supply and demand would reveal no scarcity of metalliferrous orebodies. The development and application of new technologies to treat the large tonnages of lower grade and more complex ores to be found in Canada might not, therefore, be pressing. Exceptions to this might be the adoption of technologies which can process lower grade or previous waste rock and tailings to increase revenues at otherwise marginal operations. However, in the future, new technologies will surely be required to satisfy both domestic and world supply of strategic minerals which Canada has in abundance. More pressing will be the need the develop and apply new technologies which minimize environmental impact or control impact at existing operations as public and regulatory scrutiny becomes more stringent. Biotechnological processes which might satisfy both the needs of extraction and environmental control have been proven at large scale in other countries and many more are under various levels of development.

1.3 Biotechnology and the Mining Industry

Biotechnology can be described as the rational exploitation of the activities of living cells or parts thereof, requiring an integrated multidisciplinary approach between biological and technical disciplines. Microbiology, biochemistry, botany, molecular biology, chemistry and engineering all contribute to practical applications in the extraction, manufacturing and service industries, and in environmental management. Considerable commercial success has been achieved in several sectors including, health care, agriculture, forestry and aquaculture. Applications of biotechnology in the mining industry might not be so widespread but they are not futuristic phenomena. Records indicate that the Chinese took advantage of biotechnology in the recovery of copper as early as the 3rd century BC (2). Of course, at that time, their understanding of the microbiological oxidation reactions taking place in piles of copper ore leading to the solubilization of copper was non-existent. Indeed, although other historical accounts provide evidence of the exploitation of such reactions, it was not until 1947 that the involvement of the sulfide and iron oxidizing bacterium, *Thiobacillus ferrooxidans*, was elucidated when it was isolated from the acidic drainage of a coal mine in the eastern United States (3). In the 1950's, the same bacterium was discovered as playing an essential role in the leaching of copper from waste rock dumps (4). Since then the understanding of microbiological and biological species and their involvement in a myriad of reactions responsible for metal solubilization, precipitation, adsorption, oxidation and reduction has increased significantly.

Over the past 40 years, industry, research organizations, government laboratories, and universities in a large number of countries have participated in investigating the utilization of biotechnology applications in the mining industry. Today, several technologies are used commercially in well understood and engineered systems. Many more technologies have been demonstrated at laboratory or pilot plant scale. Although initial developments were aimed at metal extraction applications, the dramatic increase in environmental awareness, the practice of sound environmental management demanded by increasingly stringent regulations over the past decade, and the need for low cost

treatment in perpetuity, has led to serious investigation of biotechnology for environmental control. It is perhaps this area in which biotechnology will play the most significant role of all applications in the future.

Some milestones in applications of biotechnology in mining are shown in the in Table 1.1, modified from Shaffer (2).

Table 1.1. Milestones in applications of biotechnology in mining

3rd century BC	Copper bio-mining in China
before 1670	Copper bio-mined at Rio Tinto, Spain
1888	Observation of iron bioaccumulation
1890	Bacterial role in rock weathering
1947	Discovery of involvement of bacteria in acid drainage formation in mines
1950's	Work on sulfate reducing bacteria
1950's	Advances in petroleum microbiology
1954	Role of bacteria in copper leaching realized
1962	Commercial uranium bioleaching at Denison Mines in Canada
1980's	Development of refractory gold ore processes
1980's	Development of biosorption processes
1980's	Bioremediation gains attention
1984	Cyanide destruction plant at Homestake Mine, USA
1986	First commercial plant for refractory gold concentrate

1.4 References

1. Hargreaves, D., Eden-Green, M., and Devaney, J. 1994. World Index of Resources and Population. Dartmouth Publishers, Aldershot, England, 417 pp.
2. Shaffer, N.R. ,1994, Biotechnical materials. In: Industrial Minerals and Rocks, 6th edn., D.D. Carr, ed,., Society for Mining, Metallurgy and Exploration, Littleton, CO, 157-169.
3. Colmer, A.R. and Hinkle, M.E. 1947. The role of micro-organisms in acid mine drainage: a preliminary report. Science 106:252-56.
4. Bryner, L.C., Beck, J.V., Davis, D.B., Wilson, D.G. 1954. Microorganisms in leaching sulfide minerals. Ind. Engng. Chem. 46, 2587.

CHAPTER 2

DESCRIPTION OF THE TECHNOLOGIES

2.1 Introduction and Classification of Processes

Biotechnologies used, under development or proposed for use in the mining industry are classified into seven groups as follows:

1. Base metals and uranium leaching
2. Gold and silver processes
3. Metal recovery from solution
4. Environmental control
5. Desulfurization of fossil fuels
6. Bioreagents for process applications
7. Applications for industrial minerals

Technologies within each group will be discussed in turn below, with further sub-classifications presented in the summary of each group to indicate the current status of a specific technology as follows:

1. Commercial
2. Nearing commercial application
3. Technically proven at pilot scale
4. Technically proven at laboratory scale
5. Preliminary development or conceptual stage

A review of the literature from the past 30 years would reveal that a very large number of process possibilities have been considered for metal extraction and environmental control in the mining industry. The review and referencing of technologies in this Chapter has, therefore, been restricted to those considered to be of particular commercial relevance and significance. The source material provided in Appendix II will provide the reader with opportunities for more extensive reading.

Further details of commercial, some near-commercial and promising technologies are given in Section 2.10 to provide information on the following factors:

- Applications
- Sector affected
- Principles of process
- Status of development
- Products
- Environmental implications
- Competing technologies
- Advantages
- Limitations
- Needed developments
- Owner of technology
- Patents
- Key references

2.2 Base Metals And Uranium Leaching

2.2.1 Summary

Applications of biotechnology for base metal and uranium extraction from ores or concentrates rely on the ability of specific bacteria to oxidize mineral sulfides under acidic conditions resulting in the solubilization of the contained metal in leaching processes. In addition, the bacteria can oxidize soluble ferrous iron to produce acid ferric sulfate which can also oxidize mineral sulfides to release contained values. Metals can be recovered from solution using conventional technology. Biotechnological processes to recover metals from solution might also be applicable. The status of processes for base metals and uranium are as follows:

Commercial	Dump leaching of wastes and low grade ores for copper Thin layer leaching of copper ores In-situ/in-place leaching of uranium Heap leaching of copper from gold ores
Nearing commercial application	Stirred tank leaching of chalcocite ore
Technically proven at pilot scale	In-situ/in-place leaching of copper and zinc sulfide ores
Technically proven at laboratory scale	Primary leaching of copper concentrates in stirred tank reactors (STR's) Catalyzed leaching of copper concentrates in STR's. Leaching of copper ores and concentrates using thermophilic bacteria Primary leaching of zinc concentrates and ores in STR's Cobalt leaching from ores and tailings Nickel leaching from concentrates and low grade materials Leaching of other base metals from low grade materials (eg zinc, molybdenum)

2.2.2 Copper

Copper bioleaching is the single largest application of biotechnology in the mining industry. All the copper sulfide ores are susceptible to bacterial oxidation, although some minerals oxidize faster and to a greater extent than others. Chalcocite and covellite are very amenable to leaching. In contrast, chalcopyrite exhibits slow kinetics and often poor recoveries. Other copper minerals have an intermediate leaching response. High recovery from copper minerals containing arsenic and antimony such as tennantite and tetrahedrite can be difficult to achieve due to the inhibitory effects of the accessory elements. Oxide copper ores occurring with the sulfides are solubilized in the acidic conditions. A significant reason for the success of bioleaching for copper has been the ability to recover the metal from solution using the widely used solvent extraction - electrowinning technology.

Dump bioleaching of copper, in which large tonnages of waste or marginal ore which would otherwise be uneconomic to treat are leached, has provided a very significant contribution to the total copper produced in the western United States (1, 2). Today, dump bioleaching is used throughout the world,

with significant developments in Chile. In Canada, exploitation of the large quantities of waste rock from open-pit copper mining, particularly in British Columbia, is limited by the alkaline nature of the country rock. Although it has been estimated that in excess of 4 billion pounds of copper exist in the mine dumps of British Columbia (3), only the Gibraltar Mine in central B.C. is using dump bioleaching commercially. A major reason for the limited use is the high acid consumption of many B.C. wastes. The recovery of copper from the pregnant leach solution is typically achieved using solvent extraction - electrowinning although some plants still use iron precipitation technology.

Thin layer bioleaching is a recent development originally developed for oxide copper ores by Sociedad Minera Pudahuel (SMP) in Chile (4). In this process, secondary copper sulfide ores are crushed and piled in low heaps and bioleached in a planned load-unload sequence. The recently commissioned large tonnage operations of Quebrada Blanca (Cominco) and Cerro Colorado (Rio Algom) in Chile will use this technology for the sulfide (primarily chalcocite) ores. The Quebrada Blanca plant will treat 17,300 t/day and projected recoveries will be 80-90% from sulfide ores to produce 75,000 t Cu per year (5).

Heap leaching of copper from gold ores. The presence of copper in gold ores creates a problem in the cyanide leaching of the gold due to high reagent consumption. At the Mt. Leyshon operation in Queensland, Australia, approximately 500,000 tonnes per year (20% of the mine output) is bioleached in heaps to remove copper, occurring primarily as chalcopyrite, prior to a cyanidation leach (6). Copper is recovered by cementation with iron.

Stirred tank applications: The recent success of stirred tank biooxidation processes and the subsequent availability of operating data for the treatment of refractory gold concentrates (see section 2.3) is leading to a renewal in the interest of stirred tank applications for copper and other base metals.

Primary bioleaching of copper ores and concentrates using stirred tank reactors to achieve faster kinetics is technically possible but has not been considered beyond laboratory scale due to lower recoveries from predominantly chalcopyrite feeds and the superior economics of conventional smelting technology. Bioleaching of chalcopyrite concentrates in the presence of catalytic amounts of ions such as silver has produced better kinetics and high copper recoveries in detailed laboratory investigations (7). The use of bacteria which oxidize sulfides at higher temperatures (40-90°C) have been shown in laboratory investigations to have potential for the processing of copper concentrates (8).

An application of stirred tank bioleaching for supplemental recovery of copper is proposed for the Zaldivar project of Placer Dome Inc (9). In the main process circuit, ore will be crushed in water-flush crushers to remove fines. Bioleaching of the fines, containing some 5% of the feed copper as chalcocite, is under serious consideration.

In-situ leaching: The bioleaching of copper ores in-situ has continued to receive interest from several mining companies. Detailed studies and field trials have been carried out in Canada (10), Australia (11), South Africa (12) and elsewhere (2) to evaluate economic and technical aspects. The economic

viability of in-situ leaching would depend to a high degree on whether extraction is to take place from a new orebody or from existing mining development. In the former case, a study by Noranda (10) showed that development costs by traditional mining methods would likely make the overall costs of metal recovery prohibitively high. Requirements for successful application include existing infrastructure (eg. hydrometallurgical plant), low iron content of ore, and mixed oxide-sulfide ores. Coupling in-situ bioleaching with less expensive ore fracturing methods and underground recovery systems should be evaluated in the long term. Environmental concerns for the in-situ method of recovery might lead to difficulties in permitting.

2.2.3 Other base metals

Nearly all base metal sulfide minerals are susceptible to bioleaching. As with the copper minerals, kinetics and metal recoveries can vary widely. Laboratory investigations continue to demonstrate that good metal extraction can be achieved. In many cases, preferential dissolution of more-valuable metal sulfides (for example, Co, Zn, Ni) can be achieved over non-valuable minerals such as pyrite. Commercial application has not, however, been considered in the past due to the superiority of conventional technologies, lower metal prices, and a lack of commercial experience with technology to recover metals such as zinc from low-concentration solutions.

As with copper, interest in zinc, nickel and other base metal bioleaching has become greater as commercial experience with refractory gold concentrates is obtained. In addition, technology for metal recovery from solution continues to develop. For example, zinc recovery from solutions containing 1-5 g/L Zn is now possible by SX-EW, although reagent prices per unit metal recovered are higher than for copper. Electrowinning grade solutions can be readily obtained in the bioleaching of zinc concentrates.

Genmin in South Africa have investigated the bioleaching of nickel and have reportedly developed a process they call the BioNic process (13) although details are lacking. Cobalt sulfides are very amenable to bioleaching and can be leached preferentially from pyritic ores. The projected future strategic importance of this metal might lead to a consideration of bioleaching of ores and tailings.

Integrated bioprocessing of complex base metal sulfide ores has been proposed (14) in which base metals and gold can be liberated from the ore or concentrate followed by biorecovery of the base metals using sulfate reduction (see section 2.3). Gold would be recovered by conventional cyanidation. Waste streams would also be biotreated.

2.2.4 Uranium

Bioleaching of uranium depends on the solubilization of the metal following oxidation by bacterially produced ferric ions of insoluble U^{4+} to soluble U^{6+}. Bioleaching has been applied successfully for extraction of uranium from operations that have previously practiced conventional mining and ore processing. Two practices have been employed. One involves spraying underground workings with water, allowing bacterial oxidation to take place, and then respraying to wash the solubilized uranium into sumps for recovery. The other practice involves flooding underground workings to promote bacterial oxidation. In Canada, Rio Algom have used both practices to recover very significant

quantities of uranium from their Elliot Lake operations (15). In 1987 it was estimated that in excess of 940,000 pounds of uranium were recovered from leaching operations, amounting to 20% of total production. The bioleach is no longer in operation since the mine is closed.

With the demise of the nuclear power industry and poor metal prices, few commercial applications are practiced and little opportunity is foreseen for the future.

2.3 Gold and Silver Processes

Commercial biooxidation plants are operating in South Africa, Brazil, Australia and Ghana for the treatment of sulfide-refractory gold flotation concentrates to liberate gold for conventional cyanidation recovery, although no plants have been considered in North America (16). The bacterial oxidation mechanism is essentially the same as that applied to the leaching of base metal sulfides. Gold recovery from carbonaceous-sulfide-refractory ores can be improved by mitigating the adsorption of gold on the carbon component of the ore in the cyanidation stage. Processes to liberate gold from strictly carbonaceous ores by degradation of the carbonaceous material are under investigation.

2.3.1 Summary

Commercial	Biooxidation of refractory gold concentrates in STR's using mesophilic and moderately thermophilic technologies. Heap leaching of copper from gold ores
Nearing commercial application	Heap oxidative leaching of low grade refractory gold ores
Technically proven at pilot scale	Heap oxidative leaching of carbonaceous-sulfide refractory gold ores Heap bioleaching of copper from gold-copper ores to reduce cyanide consumption
Technically proven at laboratory scale	Biooxidation of refractory ores in STR's Thermophilic biooxidation of refractory ores
Preliminary development or conceptual stage	Biooxidation of carbonaceous refractory ores Direct solubilization of gold using cyanide-producing bacteria

2.3.2 Sulfide-refractory ores and concentrates

The dramatic increase in the price of gold in the early 1980's led to consideration of the metallurgically-complex refractory gold ores as a source of the precious metal in addition to the free-milling ores. The sulfide-refractory gold ores contain gold in intimate association with sulfide minerals, typically pyrite and arsenopyrite. Gold is not liberated for recovery by conventional cyanide leaching even by very fine grinding. Sulfide oxidizing bacteria solubilize the host minerals, releasing the gold for conventional recovery. The principles of processes for biooxidation of sulfide-refractory gold ores and concentrates were the subject of a recent review. (17).

Stirred Tank Applications: Today, three technologies are used commercially to treat sulfide-refractory ores and concentrates: roasting, pressure oxidation and biooxidation. To date, there are six commercial biooxidation plants in South Africa, Australia (3 plants), Brazil and Ghana. The largest biooxidation plant at the Sansu Project in Ghana, treats 760/day tonnes of refractory concentrate in three parallel reactor trains of three reactors each. Expansion of the plant to four reactor trains is planned.

Unlike the first five plants which utilize more conventional mesophilic bacteria (predominantly *Thiobacillus ferrooxidans*) at 35-40°C using Genmin's BIOX® licensed technology (18), the latest plant at the Youanmi mine in Australia utilizes moderately thermophilic bacteria at 45-50°C (19). The São Bento plant in Brazil is worthy of note in that it uses a combination biooxidation - pressure oxidation plant to treat refractory concentrate (18). Biooxidation is used initially to oxidize the more readily oxidizable sulfides and to the reduce the amount of CO_2 generated in the subsequent autoclave stage due to reaction of carbonates with acid which would lower the oxygen overpressure.

All the commercial biooxidation plants treat concentrates, although treatment of ores has been shown to be technically feasible. The refractory sulfide flotation concentrates are oxidized in a multi-reactor (STR) train to the degree required for gold liberation. An advantage of biooxidation over the competing technologies is that for many ores, particularly those in which gold is associated with arsenopyrite, complete oxidation is not necessary to achieve high gold recovery. This is due to a preferential oxidation of the arsenopyrite over pyrite. Oxidized residues are separated from the leachate for recovery of gold by cyanidation. Solutions are treated with lime to form iron and arsenic precipitates which have been shown to be environmentally stable under commercial operating conditions (20).

Engineering and R and D capability to design, construct and operate plants exists in Canada. Several significant pilot plant campaigns have been carried out by Canadian firms in Canada and elsewhere (16).

A patent exists for the use of thermophilic bacteria for sulfide-refractory ores (21). These bacteria operate at much higher temperature and might find application in the future (8), although the robustness of the thermophiles when subjected to high density pulps in stirred reactors has been questioned (22).

Heap Biooxidation: Biooxidation to recover gold from low grade refractory ores in heaps has been extensively tested and piloted by Newmont and others in Nevada. The Newmont Gold Company and Newmont Mining Corporation hold patents covering aspects of the biooxidation heap pretreatment and leaching processes including the inoculation/agglomeration of the ore and subsequent gold leaching stage using thiosulfate in place of cyanide for biooxidized carbonaceous-sulfidic ores (23, 24, 25). The construction and operation of commercial heaps is imminent by Newmont. Barrick Gold Corporation is collaborating in the Newmont efforts and expect to construct a large scale heap in the near future (26). The process is amenable for processing sulfidic ores with sulfide grades as low as

0.2-0.4%, at a cutoff grade of 1-2.3 g/t, with economic recoveries of 50-60% (27). Other companies are known to be pursuing commercial application in the United States although details are limited.

A related application of heap bioleaching can be found at the Mount Leyshon mine in Australia (6) where bioleaching has been developed to remove copper from a copper-gold ore prior to cyanidation to reduce cyanide consumption. This application was discussed previously in Section 2.2.2.

2.3.3 Carbonaceous-sulfide and carbonaceous refractory ores

Even though gold might be liberated from the sulfide matrix during oxidation, gold recovery from carbonaceous-sulfide refractory ores is often prevented due to adsorption of the gold-cyanide complex onto the carbonaceous material during the cyanidation stage (preg-robbing). Laboratory tests have indicated that biooxidation can reduce the preg-robbing effect due to microbial or enzymatic processes rendering the carbonaceous material inactive (28). The same effect is likely to improve gold recovery during the heap leaching of such ores as in the Carlin Trend of Nevada.

Gold occurring within the carbon matrix of the non-sulfidic carbonaceous ores is more difficult to recover using a microbiological approach and commercial application appears at this time to be unlikely. However, two patents have been issued for processes which claim to alter the properties of the carbon and allow gold recovery by cyanidation (29, 30).

2.3.4 Direct gold leaching by cyanide-producing bacteria

Microorganisms that produce cyanide and other compounds which can lead to the dissolution of gold are known (31). Process development is at a conceptual stage.

2.3.5 Recovery of silver from manganiferrous-silver ores

Silver recovery from manganiferrous ores using cyanide is impractical due to high reagent consumption and silver occlusion in the manganese. Two biological approaches have been conceived to process such ores: (a) leaching the silver, manganese or both, and (b) reducing Mn^{4+} to Mn^{2+} to liberate the silver (32). However, notwithstanding depressed metal prices and suitable alternative technologies, development beyond the conceptual/laboratory stage appears unlikely.

2.4 Metal Recovery from Solution

2.4.1 Summary

Metal recovery from solution using biotechnology can be achieved via a number of mechanisms including biosorption, reduction and precipitation. Processes could be used to win metals to increase revenues as a stage in a conventional or biohydrometallurgical extraction process or be employed for environmental control. In many cases, both purposes could be achieved by the same process. Since metal-winning using biotechnology has not been applied commercially, discussion of the various

technologies will be brief in this section. More emphasis is currently focused on environmental control and these applications will be discussed in Section 2.5.

Technically proven at pilot scale	Biosorption of uranium from bacterial leach solutions Recovery of selenium by selenite reduction
Technically proven at laboratory scale	Active sulfate reduction and recovery of metals as sulfides Biosorption of metals including gold, chromium, cadmium, copper, zinc Selenate reduction to selenium

2.4.2 Biosorption

Biosorption relies on the fact that live or immobilized biomass can absorb metals from leach solutions or waste streams in processes known as biosorption. Considerable research and development has been carried out to evaluate biosorption for metal winning, although no commercial success has been achieved to date. Much of the pioneering and advanced development work has been carried out in Canada (33,34) Most of the emphasis on biosorption has, however, been placed on the environmental control aspects, with several companies established in the 1980's to attempt to commercialize technology.

For metal winning, applications of biosorption processes have not achieved success in the mining sector due to a number of factors including: the lack of selectivity of biomass; and the difficulties of using the technology to recover metals from large volume, low concentration solutions from disperse sources as often encountered at mining operations (35). More recent focus has been on applying the technology for higher concentration, point sources such as produced by other industrial sectors including metal finishing and plating operations.

2.4.3 Other processes

Selenium Recovery: Under the NRC-IRAP program, a CANMET process using rotating biological contactors (RBC's) to recover selenium from a weak acid effluent containing selenite discharged from a base metal smelter was piloted (36). Reduction of selenate to selenium is also possible and has been demonstrated in the laboratory (37).

Sulfate Reduction: Precipitation of metals occurring in sulfate solutions as sulfides under anaerobic conditions is a well documented and understood process which occurs in nature in wetlands and other environments. It is one of the principal mechanisms exploited in processes for *passive* environmental control using natural and engineered wetlands to be discussed in Section 2.5. In addition, significant work has been carried out in Canada to develop an *active* sulfate reduction process using reactor technology to achieve rapid kinetics (38). This process, named the BioSulfide Process, uses a novel approach to prevent the eventual slowing of reactions due to the intimate mingling of the biomass and sulfide precipitates. Hydrogen sulfide produced by sulfate reduction in the 2nd stage is used to selectively precipitate metals in the 1st stage so that the sulfate reduction stage is performed on a

metal-free solution. Further development is required to demonstrate this technology at a larger scale. The commercial success of the biological sulfate reduction plant at the Budelco BV zinc refinery in the Netherlands (39) illustrates the potential of this type of process for achieving simultaneous metal recovery and environmental control (see Section 2.4.4).

2.5 Environmental Applications

2.5.1 Introduction

Mining and mineral processing operations are not environmentally benign and the industry has to consider present and future needs for effluent control using environmentally-friendly processes as well as dealing with the massive clean up required from past operations. Environmental concerns include cyanide in aqueous discharges; closure of spent cyanide heap leach piles; the disposal of wastes with acid rock drainage potential; the treatment of high-volume groundwaters, tunnel discharges, surface runoffs, and mine dewatering flows containing low concentrations of contaminants, including the problems of acid rock drainage associated with each; the disposal of iron-arsenic wastes and precipitates; the settling of suspended particulates in process streams; the degradation of organics; general concerns related to water management; and projected difficulties in meeting future discharge regulations. In summary, the contaminants of primary concern in mining waste waters are:

- cyanide and related compounds
- heavy metals (particularly related to acid rock drainage) and radionuclides
- arsenic
- thiosalts
- ammonia and nitrate
- organics
- suspended solids

Biotechnological approaches for environmental control are under various stages of development, with some commercial applications, or have been proposed for all of the above contaminants. There are two broad groups of application: active and passive treatment. In active treatment, a biotechnological plant would be designed and operated according to typical mineral processing or chemical engineering principles to maximize the rate of pollution mitigation by optimizing the metabolic activity of the microbiological or biological species involved. Such plants would require ongoing infrastructure, personnel, process control and maintenance as would any conventional treatment facility. Passive systems rely on the activity of the microbiological or biological species within a natural setting. Mechanisms of contaminant removal are numerous and can include hydroxide precipitation in aerobic conditions, sulfide and carbonate precipitation in anaerobic conditions, filtration of suspended material, metal uptake into biomass, ammonia-generated neutralization and precipitation, and adsorption and exchange with plant and other biological materials (40). Some engineering of these natural systems is possible, although they are ideally self supporting, requiring only simple control, periodic maintenance and monitoring.

Biotechnological processes have potential for the treatment of multi-pollutant streams. Von Michaelis (41) provided an overview of the potential of biotechnology for environmental control in 1985 and which is still a useful introduction to some of the possibilities. A recent report by Kilborn Engineering (42) has evaluated passive technologies of potential interest to the mining industry. A recent analysis compares the costs of passive (biotechnological) treatment and conventional lime treatment for some operations in the U.S. (40).

2.5.2 Summary

Commercial	Cyanide and ammonia destruction and metal removal at the Homestake Mine, South Dakota Active sulfate reduction for groundwater remediation Limited use of engineered wetlands for polishing Limited success of biocides in waste piles to control bacteria causing ARD generation In-situ cyanide degradation in spent heap leach piles
Technically proven at pilot scale	Biosorption of uranium from bacterial leach solutions Recovery of selenium by selenite reduction Biosorption of metals including , chromium, cadmium, copper, zinc, arsenic Ecological engineering approaches using plant growth for solution polishing ARUM Process (acid reduction using microbiology), a specific ecological engineering approach, for metal removal and alkalinity generation Thiosalt treatment by biooxidation Selenate removal by reduction Degradation of oxalate (from the Bayer Process)
Technically proven at laboratory scale	Active sulfate reduction and recovery of metals as sulfides from acid rock drainage (BioSulfide Process) (mini-pilot) Passive sulfate reduction of acid rock drainage USBM BioFix Process Microbial-based technology to produce iron arsenate compounds with long-term stability Thiosalt treatment by bioreduction Nitrate removal from effluents Degradation of ethylene glycol Degradation of phenolics
Preliminary development or conceptual stage	Bioplugging to seal tailings surface for ARD control Production of microbial polymers for flocculation and agglomeration of suspended solids Degradation of organic mineral processing reagents in process streams PHITO Process (phosphate heterotroph inhibition of oxidation) to stabilize tailings

2.5.3 Cyanide destruction

Engineered processes: Conventional processes for cyanide destruction such as the use of hydrogen peroxide or SO_2-air, or by simply allowing natural degradation to occur in the tailings pond, are still widely used and provide efficient and cost-effective technologies. The use of biotechnology for cyanide destruction has found only one notable application at the Homestake Mine in Lead, South Dakota (43).

Degradation of cyanide and related species such as ammonia and thiocyanate is readily accomplished microbiologically. The Homestake process employs mechanized removal of CN and SCN from mine water and tailings pond decant in a 2-stage process. In the 1st stage, CN and SCN are converted to NH_3 and CO_2. Metals, including ferrocyanide, are absorbed into a biofilm which is recovered and disposed of the tailings impoundment. In the 2nd stage, nitrification takes place, converting NH_3 to NO_2 and NO_3. Concerns with the process are that refractory metal-cyanide complexes are not degraded and the long-term stability of ferrocyanide complexes.

After 10 years of operation the performance of the Homestake plant continues to improve both through operating efficiencies and through evolution of the micro-flora. Minimal power costs are the major treatment cost (44).

The USBM have carried out field trials for detoxification of heap leach solution containing low CN levels using bacteria growing on activated carbon in tanks during operations closure (45). Cyanide is oxidized as the process solution is passed through the tanks before being returned to the heap leach piles.

In-situ cyanide degradation: Use of biological cyanide degradation during the decommissioning on heap leach piles has had some success in the United States being operable under variable physical, chemical and mineralogical conditions (46). Cyanide degradation in heaps is relatively easy to achieve at low cost and requires, in many cases, only the addition of phosphate to enhance bacterial activity (47). The removal of heavy metals from effluents associated with spent ore piles represents a more serious challenge. In a system termed Biopass, cyanide and metal-contaminated solutions from spent piles can be passed through a lined solution pond designed to provide cyanide removal by biological degradation and evaporation, and also to act as a static upflow anaerobic reactor for metal removal by sulfate reduction (47) (see section 2.5.4).

2.5.4 Heavy metal removal

Heavy metal contamination of process streams, plant effluents and runoff/seepage from waste impoundments is a major concern in the industry. Of particular importance is the contaminated drainage resulting from the generation of ARD in mine waste rock, tailings, in open pits and in abandoned underground workings. Conventional lime treatment works well and is justifiably favoured by the industry for heavy metal removal and pH control. Problems with sludge disposal from lime treatment have, however, led to the evaluation of alternative approaches to removing metals from various streams. In addition, future projected regulations concerning effluent discharge might be difficult to meet using lime treatment, particularly with regard to sulfate.

The major developmental hurdles are related to the often very large volumes of solution to be treated and the associated difficulties with developing biological processes with the rapid kinetics required to reduce plant requirements to a practical size. In addition, the concentration of metals and other ions in some process streams and in many acidic drainages are inhibitory to some biotechnological processes.

Sulfate Reduction: For primary treatment, sulfate reduction has received the greatest attention. Objectives for sulfate reduction are usually related to metal removal and alkalinity generation but can also be carried out to reduce sulfate concentrations. At this time, sulfate is not regulated in North America to low levels and the interest has primarily been metal removal and alkalinity generation. In other jurisdictions, for example in the Netherlands, sulfate is regulated more stringently and the interest is in all process capabilities.

A plant was commissioned in the Netherlands in 1992 at the Budelco BV zinc refinery to treat groundwater contaminated with sulfate and heavy metals (39, 48). The plant was designed to treat 7000m^3/day of groundwater containing 230 mg/L Zn, 1200 mg/L SO_4, and with minor quantities of other metals. Effluent concentrations of <0.3 mg/L Zn and <160 mg/L SO_4 are reported. The solution to be treated at Budelco represents a lightly contaminated feed for a sulfate reduction system relative to some of the more complex and concentrated acid drainages encountered at many Canadian operations.

Supply and cost of suitable substrates (electron-donor and carbon source) for the sulfate-reducing bacteria is an important factor in process viability. Examples of suitable substrates are lactate, pyruvate, citrate, ethanol, starch, molasses, some organic acids and mixed substrates such as sewage sludge and other organic wastes. Some bacteria can grow autotrophically on gaseous substrates such as hydrogen/CO_2 or CO. In the Budelco plant, ethanol is used as an efficient carbon source and electron donor.

Processes such as the BioSulfide process being developed in Canada (38), as previously discussed in Section 2.4.3, also appears to offer a realistic opportunity for a biotechnological approach. Results indicate considerable success with feed solutions more highly contaminated than at the Budelco plant. If precipitated sulfides are not recovered for revenue, they must be disposed of to prevent re-oxidation. Demonstration of active sulfate reduction for highly contaminated waters at a significant pilot scale is needed before the process can be accepted as a viable alternative. Developments required are mainly related to the engineering of large scale reactor systems. The USBM has also devoted significant research effort in a similar sulfate reduction process, although with a more passive approach (49).

Biosorption: As previously discussed in Section 2.4.2, biosorption has been extensively evaluated in Canada and elsewhere in the world for heavy metal removal for environmental control. Biomass in pelletized form can be used to adsorb metals with accumulation of up to 35% of biomass dry weight in heavy metals. Some selectivity is possible. Durability of pellets is necessary for large scale application.

In the 1980's, small entrepreneurial companies were established (50) to develop the technology to the commercial stage, but despite significant laboratory and piloting success, commercial application has not occurred. The USBM are developing a process called BioFix for treatment of ARD. In the process biological matter with an affinity for heavy metals is impregnated on polymeric beads to improve handling characteristics. Use in column or upflow filter allows maximum contact with waste stream. The columns are acid washed to remove adsorbed metals. The process has been tested in the laboratory and at least one pilot scale program. Treatment of the acid eluate solution requires further development. The process is not sufficiently developed to allow evaluation. Operating and maintenance costs are expected to be high.

Problems with commercial development of biosorption are related to high costs, lack of selectivity (loading of iron), difficulties with handling large flows, and the competitiveness of conventional and compact treatment plants. Application is limited for disperse sources such as are found on mine sites. Point source streams in other industrial applications are more favourable targets and efforts in developing the technology are focusing more on non-mining applications (35).

Engineered wetlands: Plants take up metals through incorporation into tissue structure and surface adsorption. Sulfate reducing bacteria in anoxic zones precipitate metals as sulfides. Metal uptake and precipitation is most active in growing period and natural wetlands are, therefore, not so effective in Northern winters (51). Wetlands, particularly muskeg, can also act as a filter for suspended solids. Although there are a number of limited successes of wetlands in removing metals including Asarco's Sweetwater lead/zinc operation in Missouri and at the Canamax gold mine in Ontario, not all solutions can be treated. Success is more likely if flows are small and only lightly contaminated. Retention time of water to be treated is possibly one of the most important criteria for the application of passive systems.

The efficiency and effectiveness of wetlands can be enhanced through construction methods designed to enhance plant growth and/or manage water flow (52). A constructed wetland experiment was conducted at the Bell mine in B.C.(53) although the relatively short evaluation period did not permit conclusions regarding process potential or cost estimates for this site. Large tracks of muskeg in Northern Ontario have potential through modification to maximize efficiency. It should be noted that many wetlands are unsuitable for heavy metal removal since they can provide critical habitat for wildlife and rare plants. There are also long term implications for heavy metal accumulation relative to hazardous waste regulations. Large land areas are required to achieve successful metal removal. For example, using suggested loading factors of 3 to 10 g Fe removed per day per m^2 of constructed wetlands (52), the treatment of 3 million m^3/year of acid rock drainage containing 0.5 g/L metals would require an estimated 40-100 ha of wetland.

Ecological Engineering: Using an engineered approach to the development and enhancement of natural metal-uptake phenomena is not restricted to wetlands. Considerable research and development work by Boojum Research and others in Canada and elsewhere in the world has shown that contamination in effluent streams can be reduced significantly through the development of engineered

micro-and macro-biological systems (54). Such systems have been termed ecological engineering. Such approaches enhance the natural water cleansing processes mediated by microbial action in lake and wetland sediments.

Boojum Research of Toronto have developed a number of systems (54). In the ARUM Process (Acid Reduction Using Microbiology), sulfate and iron-reducing bacteria reduce acidity and cause metals to precipitates under anaerobic conditions. The bacteria use cattail litter and organic substrates as carbon sources. In the CHARA Process, a species of algae demonstrates an affinity for ^{226}Ra in uranium tailings effluents. These types of processes have been shown in large pilot projects to be effective in reducing metal concentrations in polishing ponds through various mechanisms including biosorption, complexation with organic mater, ion-exchange, precipitation and uptake. Nitrogen removal using cattails is also possible with loadings of 1 tonne N/ha/year claimed (55).

Experience at Canadian mining sites undergoing decommissioning indicates that passive, ecological engineering approaches to water decontamination is feasible (56). Microbial metal removal processes continue in lake and wetland sediments even under harsh winter conditions.

A field trial at the airport in Halifax, Nova Scotia, based on sulfate reduction in a passive system to treat acidic drainage, yielded mixed results (56).

2.5.5 Arsenic

Arsenic is conventionally removed from solution using lime in combination with ferric chloride or sulfate precipitation. Biotechnological approaches are under development including sulfate reduction processes as previously discusses in Section 2.5.4.

Microbial-based technology to produce iron arsenate compounds with long-term environmental stability have been evaluated (57). Significant removal of arsenic by muskeg sediments in laboratory and field experiments has been reported (58).

2.5.6 Thiosalts

Thiosalts can be present in process streams due to oxidation of sulfides, particularly pyrrhotite, during the milling process. Following discharge to the environment, thiosalts have the potential to create impact since they can be oxidized to sulfuric acid. Biotechnological approaches to thiosalt treatment include oxidation and reduction systems. Work is in progress at CANMET to develop a biological reduction approach (59). Previous investigations, including pilot plant trials, to develop chemical and biotechnological approaches to thiosalt treatment at CANMET have been summarized (60).

2.5.7 Ammonia and nitrate

Ammonia and nitrate/nitrite in mine waters can be in high concentration due to the use of mining explosives. Nitrate/nitrite has not been previously regulated, but impending regulation has led to attempts to apply a biotechnological approach to meeting standards. The Homestake cyanide

destruction plant, previously discussed in Section 2.5.3, has shown that ammonia can be effectively removed under large scale commercial conditions (43). Biological nitrification/denitrification can be achieved in a 2 stage process: 1. ammonia is converted to nitrite and then nitrate under alkaline conditions; 2. reduction of nitrate to nitrogen gas and water in absence of oxygen. Ammonia is not readily removed by conventional technology and reliance is often placed on natural degradation to reduce concentrations.

Biotechnological processes are currently under investigation at CANMET and within the private sector for ammonia removal (59). The CANMET process has been tested at pilot-scale at a mine site

2.5.8 Organics

The mining industry uses a large number of organic compounds including flotation reagents, fuels, lubricants, antifreeze, de-icing fluids and heat-exchanger additives. In other cases, metals processing can produce organic contamination of process waters. Organic contamination of waters has environmental implications and can affect the quality of water recycled to the mineral processing plant. Numerous laboratory studies have been undertaken by CANMET and others to investigate the removal of organics from effluents and recycle waters (36). Some success has been achieved in breaking down phenolics (resulting from the use of frothers), oxalate (from the Bayer Process for aluminum), urea, triethylene glycol, and ethylene glycol.

A patented process developed at CANMET for the removal of oxalate was piloted by Alcan for 1½ years, removing 0.2 t/d oxalate from a process stream in the Bayer Process (61, 62).

Considerable work conducted within the oil industry sector has shown success in the degradation of various petroleum products and refinery sludges (63).

2.5.9 Suspended Solids

Mechanical settling, tailings ponds and settling ponds in combination with chemical coagulants and flocculants are conventional approaches to the removal of suspended solids in effluents required for environmental control and to improve the quality of water recycled to the processing plant. The Biotechnology Group at CANMET is currently carrying out laboratory investigations to evaluate a number of microbially produced agents for their coagulating, agglomerating and flocculating properties (59).

The ability of wetlands to act as a filter for suspended solids has already been discussed.

2.5.10 Applications to solid wastes

Prevention of acid rock drainage generation in tailings is an environmental priority in the mining industry. Conventional approaches to prevention and control include dry covers, water flooding and base addition. Biotechnological approaches to prevention have received some attention and are under laboratory investigation. Bioplugging, the in-situ generation of an oxygen consuming layer of

microbial expolymer around the periphery and over the surface of tailings, has been evaluated at small scale with some encouraging preliminary results (64). Scale up problems are, however, likely to exist. In another experimental process (PHITO, phosphate heterotroph inhibition of oxidation), it is proposed to form an insoluble, low permeability layer in fresh tailings (55). Acid generation could be reduced through the formation of the layer combining a vegetative cover (to facilitate the growth of oxygen-consuming bacteria) with phosphate rock integrated into the tailings vadose zone.

The use of inhibitors to prevent the activity of *Thiobacillus ferrooxidans* has also been studied (65). Specific non-toxic inhibitors of sulfide oxidation in neutrophilic Thiobacillus species for the prevention of acidic drainage in fresh tailings are currently being studied at the laboratory scale at CANMET (66).

2.6 Fossil Fuels

2.6.1 Summary

Desulfurization of fossil fuels (coal, oil, oil shales, flue gas), offers a vast potential market for biotechnology. Sulfur can occur as inorganic sulfide (primarily pyrite and pyrrhotite), sulfate and organic forms. Driven by the potential, a number of countries have carried out large, state-sponsored research and development projects in this area. Other biotechnological applications are in use or have been proposed for use in the oil sector.

Commercial	Microbially enhanced oil recovery Biopolymers as a drilling aid to improve oil recovery Microbial dewaxing of oil wells Site remediation to degrade hydrocarbon contaminated soils Land farming of oily wastes Treatment of liquid effluents in refinery and petrochemical operations Use of biocides to control fouling and corrosion in water and other fluid handling systems
Technically proven at pilot scale	Removal of inorganic sulfur from coal and other fossil fuels Microbially-enhanced fracturing of oil formations Bioremediation of slop-oil and oil spills Removal of organic sulfur from liquid fossil fuels Microbial plugging to prevent mud loss and enhance oil recovery Microbial surfactants and emulsifying agents to improve oil transportation in pipelines Removal of organic sulfur and H_2S from gaseous emissions
Technically proven at laboratory scale	Removal of SO_2 from flue gas Removal of SO_2 and NO_x from flue gas
Preliminary development or conceptual stage	Removal of organic sulfur from coal

2.6.2 Desulfurization of coal

It has been shown in numerous studies that inorganic sulfide sulfur can be removed by bacterial oxidation using mesophilic and thermophilic bacteria (67). In addition, alteration of surface properties of pyrite in coal using a short residence time bioleach to facilitate its removal by oil agglomeration has been demonstrated in the CANMET laboratories (68). Organic sulfur removal is much more challenging and biotechnological approaches are questionable.

Despite the potential and the technical demonstrations at laboratory and pilot scale, commercial applications are limited by a number of important factors. On the process side, considerable difficulties need to be overcome to demonstrate that reactor systems to handle the high volumes of material to be treated can be engineered and provide the necessary kinetics. Difficulties will also be encountered with treating the large volumes of leachate produced from the oxidation stage. In addition, the suitability of conventional technologies, the practice of coal blending, grandfather clauses on existing permits enjoyed by utility companies, and the continued reliance on scrubbing technology would all seem to preclude consideration of biotechnology for this application. However, future regulations might require serious consideration of new technologies.

2.6.3 Desulfurization of oil and flue gas

Desulfurization of Oil: Heavy crudes, oil sands and oil shales often have higher sulfur contents than conventional crudes. A higher use of these sources of petroleum products is likely in the future and the means to remove sulfur will be required. Biotechnological approaches have shown positive results in the laboratory and removing organic sulfur from liquid fossil fuels has been piloted (69).

Desulfurization of Flue gas: Current technology for flue gas desulfurization, involving the use of limestone and dolomites for gases adsorption, produces large quantities of gypsum, presenting a significant waste disposal problem. In addition, NO_x gases are not removed. Laboratory investigations have evaluated sulfate reduction systems to remove SO_2 with some positive results, but commercial application requires significant development of both process and engineering aspects. A process to simultaneously remove both SO_2 and NO_x has been proposed (70).

2.6.4 Other applications in the oil sector

Some biotechnology applications in the oil sector are now routine (69). Applications in the oil sector have recently been reviewed (63, 71) and include: treatment of liquid effluents; microbial degradation of refinery sludges and slop oil; cleanup of hydrocarbon-contaminated soils; microbially-enhanced oil recovery; microbial plugging of porous or fractured zones during drilling; microbially-enhanced fracturing of formations; microbial dewaxing of oil wells; biocides to reduce biofouling and biocorrosion.; use of biopolymers as drilling aids; microbial surfactants and emulsifying agents to improve oil transportation.

2.7 Bio-Reagents for Process Applications

The laboratory evaluation of microbially-produced reagents for coagulation, agglomeration and flocculation has already been discussed in Section 2.5.6. Additional work is taking place to develop specific reagents for possible use in flotation and for solvent extraction. Current results are, however, preliminary and commercial possibilities are difficult to assess.

Preliminary development or conceptual stage	Production of microbial reagents for applications in flotation, solvent extraction and solids settling

2.8 Applications for Industrial Minerals

2.8.1 Summary

Although very little attention has been given in the past to the potential for biotechnology in the industrial minerals sector, some laboratory investigations have been in progress for a number of years to evaluate possibilities. Such efforts have been recently reviewed (72).

Technically proven at laboratory scale	Upgrading bauxite ores using heterotrophic bacteria to leach silica Bioleaching of phosphate Inhibition of microbial corrosion of stoneworks
Preliminary development or conceptual stage	Bioleaching of rare earth elements Removal of contaminants from various industrial minerals Surface modifications of materials for improved ceramic properties

2.8.2 Leaching processes

Bauxite: Significant deposits of aluminosilicates exist which could serve as sources of aluminum. In addition, many bauxite ores are too low grade for conventional recovery due to silica dilution. The upgrading of such ores by bioleaching silica using heterotrophic microorganisms has been investigated for many years (73). Despite the efforts, commercial application is not considered to be imminent due to process difficulties, the costs of bacterial substrate, and the abundance of existing bauxite deposits. Total reliance in North America on bauxite imports, however, could result in increased emphasis in the future.

Phosphates: Phosphate dissolution using bioleaching is technically feasible but biotechnological applications are limited by the superior viability of conventional technologies.

Rare earths: Bioleaching of rare earth elements including lanthanum, cerium, praseodymium from zircon mineral has been reported. Results are very preliminary.

2.8.3 Corrosion control

Many stoneworks are subject to microbiologically-mediated corrosion. Microbes can produce sulfuric acid from sulfur compounds present in the air from the burning of fossil fuels. Such sulfur compounds can provide an energy source for the acid-producing bacteria. Products and processes to inhibit microbially-induced corrosion are being investigated (74).

2.9 Mineral Exploration

Although studied as a scientific discipline for some time, the potential for using biogeochemistry in mineral exploration has received particular attention over the past twenty years or so. Techniques for helping to identify mineral targets include a number of related disciplines including the study of plant physiology, plant-soil interactions, elemental composition of the larger plants, soil microbiology, and the relationship between soil organic matter and trace metals. A promising area of investigation has been based on metal toxicity to soil microorganisms. Resistance to specific metals, normally toxic to microorganisms, is related to the occurrence of elevated levels of specific metals in the soil such as in the vicinity of an anomaly. Evaluation of the resistance to metal toxicity has been used to indicate the potential enrichment of these elements in the vicinity of ore deposits of many types. Such metal resistances are quite easy to test in bacterial populations and can be cheaper and easier to determine than the presence of the elements by chemical analysis if they occur in trace amounts. In a similar manner, penicillin resistance in soil bacteria has been used as an index of soil metal content over mineral deposits.

Much of the work reported in the literature is speculative in nature and a detailed account of this field will not be given here. The reader is referred to a compilation of papers on the subject (75).

2.10 Potential for Genetic Engineering

Enhanced microbial performance for improved process results can be achieved by searching for better strains or through genetic engineering. Considerable research effort has been made in Canada, the United States, Japan, South Africa and elsewhere into improving biotechnological processes through the latter approach. Recent work in Canada has been conducted, for example, at the Biotechnology Research Institute in Montreal (76). A number of areas have been investigated including mineral leaching, cyanide degradation and sulfate reduction. Characteristics of microorganisms which could be improved by this approach include:

- increased metabolic rates to produce higher reaction/leaching rates
- increased resistance to toxic and inhibiting cationic and anionic species including metals and chloride
- increased tolerance to cold temperatures for applications in northern climates

Significant developments in this field have been limited due to the requirement for a greater understanding of the basic microbiology of organisms such as *Thiobacillus ferrooxidans*. Although some very significant advances have been made in the area, genetically-engineered microorganisms are not yet available and likely will not be for several years.

The use of genetically engineered microorganisms will require careful control to prevent competing natural organisms from becoming dominant. This will likely prevent application for less controlled processes such as dump leaching, heap leaching and environmental processes which are performed in the "open". Similarly, if a process requires microbial consortia, which is frequently the case, control might be more difficult. If genetically-engineered strains are used, they would only apply to controlled plant processes. It should be noted, however, that in many of the biotechnological processes discusses in the preceding sections, process limitations might not be due to microbial factors. Many technologies are operated to conform to metallurgical considerations and are often limited by engineering constraints. For example, higher pulp densities in refractory gold biooxidation are not employed due to limitations in reactor aeration and agitation design related to oxygen mass transfer considerations. A better performing bacteria to withstand higher metal concentrations, for example, would serve little purpose in this case.

Bacteria which could tolerate higher chloride concentrations have potential in leaching operations where only highly saline process waters are available. Bioleaching in some areas of the Andes of Chile are an example. Similarly, operation of passive sulfate reduction systems in the Canadian winter would benefit by cold-tolerant bacteria. In these and other cases, development of superior strains could increase the potential for application.

2.11 Commercial Applications in Canada

Canada has been slower to adopt biotechnology at commercial mining operations compared with the United States, South Africa, Chile, Australia, countries in Europe, and elsewhere. To date, commercial scale experience is limited to the uranium bioleaching at Denison's Elliot Lake operations in the 1980's (15) and the current dump bioleach at the Gibraltar Mine in B.C. The considerable process and engineering know how in Canada in the biooxidation processes for refractory gold ores and concentrates has not resulted in commercial plants despite commercial success elsewhere (16). Several significant biooxidation pilot plant studies have been conducted in Canada.

With the exception of limited applications of wetlands and ecological engineering approaches which have been shown to be capable of reducing metal contamination at specific sites, applications for environmental control have not achieved commercial success. However, greater future use of biotechnology for a number of environmental applications is likely as legislative pressures increase. Pilot studies have indicated the technical feasibility of selenite reduction to selenium, oxalate degradation (Canadian technology applied in Jamaica), and biosorption of uranium, associated radionuclide elements, and base metals. The commercial success of a sulfate reduction plant to remediate contaminated groundwater in the Netherlands will likely create opportunities for a

technology already well developed in Canada. Considerable interest is currently being shown in larger scale demonstrations of processes for environmental control.

2.12 Details of Selected Technologies

In the following pages, further details of some selected biotechnologies are provided. In the most part, technologies are those which have been applied commercially or have been demonstrated in pilot plant operations. Some additional technologies which have not been demonstrated at large scale but which have been evaluated rigorously in laboratory investigations and might have good future potential are included.

Dump leaching of copper

Sector: Base metal

Applications and Issues:	Leaching of copper from waste or low grade material in waste dumps
Status:	Widely practiced in United States, Chile, Australia and elsewhere in the world. Commercial operation at Gibraltar mine in BC; significant contribution to copper production in U.S.
Principles of Process:	Mesophilic (principally *T. ferrooxidans*) and thermophilic bacteria (*Sulfolobus* sp.) oxidize copper sulfides, solubilizing copper. Pyrite is oxidized to ferric sulfate which also oxidizes minerals. Copper recovered from pregnant solutions by SX-EW or, less commonly, cementation.
Feed Materials:	Waste rock or marginal ore from copper mining
Products:	Cathode copper
Environmental Implications:	Long term implications for ARD after pregnant solutions become too low grade for economical recovery
Competing Technology:	None
Advantages:	Low cost; extends life of marginal operations; no competing technology
Limitations:	Slow process, low recoveries. very slow kinetics and recoveries for chalcopyrite
Needed Developments:	
Owner of Technology:	None
Patents:	None
Key References:	1, 2, 3

Thin layer bioleaching of copper

Sector: Base metals

Applications and Issues:	Alternative process for primary recovery of copper from secondary sulfide minerals
Status:	Rapidly developing commercial applications in Chile. Rio Algom and Cominco to use technology at recently commissioned Cerro Colorado and Quebrada Blanca operations; Placer Dome developing process for Zaldivar operation.
Principles of Process:	Ores crushed fine and stacked in low heaps and bioleached in a planned load-unload sequence. Acid agglomeration can be used to initiate leaching and improve pile permeability. Retention times typically 160 days to achieve Cu extractions >80% from chalcocite and covellite ores. Copper won from pregnant solution by SX-EW.
Feed Materials:	Secondary copper ores
Products:	Cathode copper
Environmental Implications:	Environmentally clean process. Less water consumption. Leached ore must be managed to prevent ARD in long term.
Competing Technology:	Conventional flotation - smelting
Advantages:	Lower cost; high value-added processing for countries with no smelting capacity
Limitations:	High copper inventory due to relatively slow leaching kinetics. Process does not recover by-product metals.
Needed Developments:	
Owner of Technology:	Sociedad Minera Pudahuel in Chile have considerable operating experience
Patents:	Chile patent No. 32,025
Key References:	4, 80

Catalyzed copper bioleaching

Sector: Base metal

Applications and Issues:	Alternative method for copper recovery from concentrates to achieve rapid kinetics and high copper recovery from chalcopyrite concentrates
Status:	Proven at laboratory scale; preliminary engineering analysis
Principles of Process:	Addition of catalytic amounts of silver to mesophilic copper bioleaching of concentrates in STR's to increase leach rate and recovery. Silver recovered by thiosulfate leach and recycled to bioleach. Copper recovered by electrowinning. Pyrite oxidation minimal in bioleach.
Feed Materials:	Chalcopyrite flotation concentrates
Products:	High grade copper leach solution for electrowinning
Environmental Implications:	Proper disposal of pyritic residue required
Competing Technology:	Flotation - smelting
Advantages:	Lower grade concentrates accepted. High copper recovery (>90%) compared with normal bioleach.
Limitations:	Economics currently inferior to conventional technology. Unproven at large scale. Precious metal recovery unproven.
Needed Developments:	Demonstration of high precious metal recovery; flowsheet development needed to improve acid and water balance
Owner of Technology:	BC Research has patent
Patents:	US Patent No. 4,571,387 (ref. 81)
Key References:	7, 81

Bacterial leaching of uranium

Sector: Base metals and uranium

Applications and Issues:	Recovery of uranium from pyritic low grade ores and wastes; in-place underground leaching
Status:	Commercial application at Denison Mines Elliot Lake operations. In 1987, 20% of total production from bioleaching. Not actively pursued at Denison or elsewhere due to depressed uranium market
Principles of Process:	Mesophilic and moderately thermophilic bacteria participate in the oxidation of sulfide minerals, primarily pyrite. Acid ferric sulfate produced leaches uranium following oxidation of U4+ to U6+ for recovery by conventional means
Feed Materials:	Low grade pyritic uranium ores and wastes; ore remaining in stopes after mining; or ore blasted and left in stopes
Products:	Leachate containing uranium, sulfate at low pH
Environmental Implications:	Dump and in-place leaching need solution control to minimize seepage to groundwater
Competing Technology:	None for low grade and waste ores
Advantages:	Ores too low in grade for primary treatment can be treated
Limitations:	Slow process
Needed Developments:	Improved bacterial performance at low temperatures
Owner of Technology:	None. Denison have operational experience
Patents:	
Key References:	15, 26

Biooxidation for refractory sulfide gold concentrates and ores

Sector: Gold mining

Applications and Issues:	Gold locked in sulfides, primarily pyrite and arsenopyrite, require preoxidation to liberate gold for cyanide leaching
Status:	6 commercial plants in South Africa, Brazil, Australia and Ghana. So far limited to flotation concentrates. No technical reasons to exclude ore treatment
Principles of Process:	Mesophilic and moderately thermophilic bacteria participate in the oxidation of sulfide minerals, releasing contained gold for conventional recovery. Reaction carried out in stirred tank reactors. Leachate treated to produce stable precipitates.
Feed Materials:	Typically arsenopyrite-pyrite gold concentrates
Products:	Gold-bearing residue for cyanidation; leachate containing iron, arsenic, sulfuric acid
Environmental Implications:	Disposal and stability of ferric arsenate precipitates (Genmin operating experience indicates satisfactory performance)
Competing Technology:	Fluo-solids roasting; pressure autoclaving
Advantages:	High gold recovery possible at low degree of sulfide oxidation. Economic at small scale (<2000 tpd)
Limitations:	To date, limited to flotation concentrates; large reactor volume required for ores. High degree of oxidation (longer retention times) usually required for solely pyritic feeds
Needed Developments:	Further reactor development; commercial application to ores
Owner of Technology:	Genmin have BIOX process; other process capability in Canada, U.S, Australia
Patents:	None affecting ability to implement in Canada
Key References:	16, 17, 18

Biooxidation of low grade sulfide gold ores by heap leaching

Sector: Gold mining

Applications and Issues:	Sulfidic gold ores too low in grade for roasting, pressure oxidation, or stirred tank biooxidation are currently dumped as waste
Status:	Near commercial in US at Newmont, Barrick Gold and other operations in Nevada. Related process to remove copper from gold ores in heap bioleach prior to cyanidation in Australia. Use of reagents other than cyanide following bioleach under investigation
Principles of Process:	Mesophilic and moderately thermophilic bacteria participate in the oxidation of sulfide minerals contained in heaps constructed to facilitate oxidation. Gold leached in subsequent leach stage using cyanide or other lixiviants such as thiosulfate.
Feed Materials:	Low grade arsenopyrite-pyrite gold ores
Products:	Leachate containing iron, arsenic, sulfuric acid; liberated gold in heap after bioleach
Environmental Implications:	Longer term ARD implications from spent heaps
Competing Technology:	None
Advantages:	Ores too low in grade for primary treatment can be treated. Indications that preg-robbing carbonaceous material is deactivated to some extent
Limitations:	Long retention time
Needed Developments:	Improved heap construction and water management
Owner of Technology:	Newmont hold patents on bioleach and on use of thiosulfate for leaching gold
Patents:	US Patents 5,246,486; 5,332,559; 5,354,359 (refs 23, 24, 25)
Key References:	23, 24, 25

Cyanide degradation

Sector: Gold mining, environmental control

Applications and Issues:	Cyanide complexes in mill and heap leach effluents require degrading before discharge to environment
Status:	Commercial plant at Lead Mine, South Dakota; full scale decommissioning of spent heap leach piles
Principles of Process:	Bacterial conversion of cyanide to ammonia followed by bacterial conversion of ammonia to NO_2 and NO_3; SCN degraded
Feed Materials:	Cyanide leach effluent; mine and tailings pond waters; spent heap leach piles
Products:	Water for discharges; metal-biofilm sludge (small volume)
Environmental Implications:	Improved water quality with direct discharge possible; long term stability of ferrocyanide complexes disposed of with biomass in tailings
Competing Technology:	Hydrogen peroxide; SO_2-air process; natural degradation
Advantages:	Better water quality discharge; SCN and NH_3 also degraded
Limitations:	Refractory metal-cyanide complexes not degraded; feed CN concentration lower
Needed Developments:	Microbes that degrade weak acid dissociable metal cyanide complexes; additional commercial applications
Owner of Technology:	Homestake Mining Co have know-how and operating experience since 1984
Patents:	US Patents 4,461,834; 4,440,644 (refs. 82, 83)
Key References:	43, 46

Active sulfate reduction (in-plant)

Sector: Base metal, precious metal and coal mining; smelter/refinery sites; environmental control

Applications and Issues:	Removal of sulfate and associated heavy metals in acid mine drainage, waste streams, leach solutions and contaminated groundwater
Status:	Commercial plant at Budelco zinc refinery in Netherlands for lightly contaminated groundwater (Zn and SO_4); advanced laboratory development/ mini-pilot plants in Canada and US for more highly contaminated streams (ARD)
Principles of Process:	Sulfate reducing bacteria reduce sulfate to hydrogen sulfide. Metals precipitated as sulfides. In Bio-Sulfide Process (Canada), metals precipitated in 1st stage to facilitate rapid and simple sulfate reduction in 2nd stage.
Feed Materials:	Acid mine drainage; sulfate waste streams; contaminated groundwater
Products:	metal sulfides; neutral pH solution for discharge
Environmental Implications:	Improvement in water quality
Competing Technology:	Lime precipitation
Advantages:	Might be lower cost than competing technology; lower sulfate in discharge; metals removed in easily filtered, low volume sludge; revenues from metal sulfide sludge possible
Limitations:	Not proven on large pilot scale for highly contaminated streams; supply of bacterial energy source; limited to low to medium volume flows if moderate metal concentrations
Needed Developments:	Demonstration on large scale for high contaminant loadings; development of reactor systems capable of low retention time with high volume flows
Owner of Technology:	Shell Research (UK) developed commercial process at Budelco; BioSulfide process developed by Triton Development , Vancouver, B.C.
Patents:	
Key References:	38, 39, 48

Wetlands, engineered wetlands

Sector: Environmental control

Applications and Issues:	Removal of contaminates from effluents; final polishing of water discharge
Status:	Limited success at operations in Canada, the U.S., and elsewhere; extensively evaluated in Canada
Principles of Process:	Plants in wetlands uptake metals through incorporation into tissue and through adsorption. Sulfate reducing bacteria in anoxic zones precipitate metals as sulfides; suspended solids removed by filtration
Feed Materials:	Contaminated effluents; tailings pond decants; ARD
Products:	Less contaminated water
Environmental Implications:	Heavy metal accumulations and future release of contaminated water
Competing Technology:	Chemical precipitation; active sulfate reduction
Advantages:	Passive system suitable for long term closure plans
Limitations:	Inefficient in cold climates; not suitable for high flows and high levels of contamination; large land area required; wetlands often provide critical habitat for wildlife and rare plants
Needed Developments:	Demonstration of long term efficacy
Owner of Technology:	None
Patents:	
Key References:	40, 52

Ecological engineering

Sector: Environmental control

Applications and Issues:	Removal of contaminates from effluents; final polishing of water discharge; reduction of acidity
Status:	Evaluated at numerous sites in Canada and elsewhere. Boojum Research has developed ARUM process, CHARA process and other biological polishing systems. Implementation at 3 sites (Newfoundland, North-Central Ontario and Northern Saskatchewan)
Principles of Process:	Plants and microbes uptake metals through incorporation into tissue and through adsorption. Sulfate reducing bacteria in anoxic zones precipitate metals as sulfides
Feed Materials:	Contaminated effluents; tailings pond decants; ARD
Products:	Less contaminated water
Environmental Implications:	
Competing Technology:	Chemical precipitation
Advantages:	Passive system requiring little infrastructure; suitable for long term closure plans
Limitations:	Inefficient in cold climates; not suitable for high flows and high levels of contamination
Needed Developments:	Further demonstration at mine sites
Owner of Technology:	Boojum Research and CANMET, technology licence
Patents:	
Key References:	54

2.13 References

1. Brierley, C.L. 1982. Microbiological mining. Scientific American, 247 (2), 44-53.
2. Schlitt, W.J. ed. 1980. Leaching and recovering copper from as-mined materials. Proc. AIME Conference, Las Vegas, February 26. 124 pp.
3. Pfalzgraff, C.L. and Coyne, K.R. 1986. The economics of copper dump leaching and its application to British Columbia's ores. 10th Annual Meeting of District 6 of the Canadian Institute of Mining and Metallurgy, Victoria, B.C., October 4.
4. Montealegre, R., Bustos, S., Rojas, J., Neuberg, H., Araya, C., Yañez, H., Tapia, R. and Rauld, J. 1993. Application of the bacterial thin layer leaching process to Quebrada Blanca ores. In: Biohydrometallurgical Technologies, Vol. 1. Bioleaching Processes, eds. A.E. Torma, J.E. Wey, V.I. Lakshmanan, The Minerals, Metals and Materials Society of TMS, Warrendale, PA, 1-14.
5. Drake, J. 1995. Compañia Minera Quebrada Blanca S.A., Santiago, Chile, personal communication.
6. Ellis, S.J. 1994. Bacterial copper heap leach followed by heap leach recovery of gold at Mt. Leyshon gold mine. In: Biomine 94, Chapter 8, Australian Mineral Foundation, Glenside, South Australia.
7. Lawrence, R.W., Vizsolyi, A and Vos, R.J 1985. The silver catalyzed bioleach process for copper concentrate, In: Microbiological Effects on Metallurgical Processes, eds. J.A. Clum and L.A. Haas, Metallurgical Society of AIME, Warrendale, PA, 65-82.
8. Brierley, C.L. 1994. Gold and Copper ore/concentrate bioleaching. In: Impurity Control and Disposal in Hydrometallurgical Processes. Proc. 24th Annual Hydrometallurgical Meeting of CIM. eds., B. Harris and E. Krause. Met Soc of CIM, Montreal, 371-379.
9. King, J. 1995. Placer Dome Inc, Vancouver, personal communication
10. Ismay, A., Rosato, L. and McKinnon, D. 1986. Engineering prefeasibility for in-place bacterial leaching of copper. In: Fundamental and Applied Biohydrometallurgy, eds. R.W. Lawrence, R.M.R. Branion and H.G. Ebner, Elsevier, Amsterdam, 191-213.
11. Butler, J.E., Ackland, M.C. and Robinson, P.C. 1981. Development of in situ leaching gy Gunpowder Copper Limited, Queensland, Australia. In: Interfacing Technologies in Solution Mining, ed. W.J. Schlitt, AIME, Chapter 22, 251-259.
12. Miller, P.C. 1986. Large scale bacterial leaching of a copper-zinc ore in-situ. In: Fundamental and Applied Biohydrometallurgy, eds. R.W. Lawrence, R.M.R. Branion and H.G. Ebner, Elsevier, Amsterdam, 215-239.
13. Marais, H. 1994. Genmin, Johannesburg, South Africa, personal communication,.
14. Marchant, P.B. and Lawrence, R.W. 1989. Integrated biological processing of complex sulphides. Proc. Biohydrometallurgy 89 Symposium, Jackson Hole, Wyoming, August 13-18, 205-220.
15. McCready, R.G. L. and Gould, W.D. 1990. Bioleaching of uranium. In: Microbial Mineral Recovery, H.L. Ehrlich and C.L. Brierley, eds., McGraw-Hill Publishing Company, New York, 107-125.
16. Lawrence, R.W. 1994. Biooxidation for the the treatment of refractory gold ores and concentrates - A Canadian perspective. CIM Bulletin 87(98), 58-65.
17. Lawrence, R.W. 1990. Biotreatment of gold ores. In: Mineral Microbial Recovery. H.L. Ehrlich and C.L. Brierley (eds.), McGraw-Hill Publishing Co., New York, 127-148.
18. Van Aswegen, P.C. 1993. Commissioning and operation of bio-oxidation plants for the treatment of refractory gold ores. In: Hydrometallurgy, Fundamentals, Technology and Innovation, Eds. Hiskey, J.B. and Warren G.W., Soc. Min. Met. and Exploration, AIME., 709-725.
19. Brierley, C.L. 1994. Selection of BacTech's thermophilic biooxidation process for Youanmi Mine. In: Biomine 94, Chapter 5, Australian Mineral Foundation, Glenside, South Australia.
20. Van Aswegan, P.C. and Marais, H.J. 1994. Biooxidation of refractory gold ores: the environmental, friendly process. In: Impurity Control and Disposal in Hydrometallurgical Processes. Proc. 24th Annual Hydrometallurgical Meeting of CIM. eds., B. Harris and E. Krause. Met Soc of CIM, Montreal, 353-368.
21. Hutchins, S.R., Davidson, M.S., Brierley, J.A. and Brierley, C.L. 1988. Thermophilic microbial treatment of precious metal ores. U.S. Patent No. 4,729,788.
22. Lawrence, R.W. and Marchant, P.B. 1988. Comparison of mesophilic and thermophilic oxidation systems for the treatment of refractory gold ores and concentrates. In: Biohydrometallurgy, eds. P.R. Norris and D.P. Kelly, Science and Technology Letters, Kew, Surrey, U.K., 359-374.

23. Brierley, J.A. and Hill, D.L. 1993. Biooxidation process for recovery of gold from heaps of low grade sulfide and carbonaceous sulfide ore material. U.S. Patent 5,246,486.

24. Brierley, J.A. and Hill, D.L. 1994. Biooxidation process for recovery of metal values from sulfur containing ore materials. U.S. Patent 5,332,559.

25. Wan, R.Y. LeVier, K.M. and Clayton, R.B. 1994. Hydrometallurgical process for the recovery of precious metal values from precious metal ores with thiosulfate lixiviant. U.S. Patent 5,354,359.

26. Marchbank, A.R. 1994. Applications of biotechnology in metals recovery (technical review). In: Proc. 10th Annual Meeting of BIOMINET, eds. W.D. Gould, L. Lortie and D. Rodrigue, CANMET SP94-1, 43-52.

27. Brierley, J.A. 1995. Newmont Exploration Ltd, Metallurgical Services, personal communication

28. Hutchins, S.R., Brierley, J.A. and Brierley, C.L.,1988. Microbial pretreatment of refractory sulfide and carbonaceous ores improves the economics of gold recovery. Mining Engineering, 40 (4), 249-254.

29. Brierley, J.A. and Kulpa, C.F. 1992. Microbial consortium treatment of refractory precious metal ores. U.S. Patent No. 5,127,942.

30. Portier, R.J. 1991. Biohydrometallurgical processing of ores, and microorganisms therefor. U.S. Patent No. 5,021,088.

31. Olson, G.J. 1994 Microbial oxidation of gold ores and gold bioleaching. FEMS Microbiology Letters, 119, 1-6.

32. Brierley, C.L. 1993. Mineral bioprocessing: opportunities in extractive metallurgy and environmental control. In: Opportunities for Innovation : Biotechnology, National Institute of Standards and Technology, NIST GCR 93-633, 241-255.

33. Tsezos, M. 1990. Engineering aspects of metal binding by biomass. In: Microbial Mineral Recovery, H.L. Ehrlich and C.L. Brierley, eds., McGraw-Hill Publishing Company, New York, 325-339.

34. Volesky, B. 1994. Advances in biosorption of metals: selection of biomass type. FEMS Microbiological Reviews 00 (1994) FER00405T.

35. Volesky, B. 1994. Dept of Chemical Engineering, McGill University, personal communication.

36. Gould, W.D., McCready, R.G.L., Salley, J., Rajan, S. and Chaklykoff, C. 1988. Microbial treatment of industrial effluents. In: Proc. 5th Annual Meeting of BIOMINET, ed. R.G.L. McCready, CANMET SP88-23, 39-55.

37. Lortie, L., Gould, W.D., Rajan, S., McCready, R.G.L and Cheng, K.J. 1992. Redustion of selenate and selenite to elemental selenium by a *Pseudomonas stutzeri* isolate. Appl. Environ. Microbiol. 58, 4042-44.

38. Warkentin, D. 1993. Development of the BioSulfide process. In: Proc. 9th Annual Meeting of BIOMINET, eds. W.D. Gould, D.W. Koren and S. Lord, CANMET SP93-1, 1-19.

39. de Vegt, A. and Buisman, C.J.N. 1995. Full scale biological treatment of groundwater contaminated with heavy metals and sulfate. In: Proc. 11th Annual Meeting of BIOMINET, eds. L. Lortie, W.D. Gould and S. Rajan, CANMET publication SP 95-1, Natural Resources Canada, 31-43.

40. Gusek, J.J. 1995. Passive treatment of acid rock drainage: what is the potential bottom line? Mining Engineering 47 (3), 250-253.

41. Von Michaelis, H. 1986. Integrated biological systems for effluent treatment from mine and mill tailings. In: Fundamental and Applied Biohydrometallurgy, eds. R.W. Lawrence, R.M.R. Branion and H.G. Ebner, Elsevier, Amsterdam, 311-326.

42. Kilborn Inc. 1995. Review of passive systems for treatment of acid mine drainage. Report submitted to MEND, CANMET, Natural Resources Canada.

43. Whitlock, J.L. and Mudder, T.I. 1985. The Homestake wastewater treatment process : biological removal of toxic parameters from cyanidation wastewaters and bioassay effluent evaluation. In: Fundamental and Applied Biohydrometallurgy, eds. R.W. Lawrence, R.M.R. Branion and H.G. Ebner, Elsevier, Amsterdam, 327-339.

44. Whitlock, J.L. 1995. Geobiotics Inc,. personal communication.

45. Lien, R.H. and Altringer, P.B. 1993. Case study: bacterial cyanide detoxification during closure. In: Biohydrometallurgical Technologies, Vol. II. Fossil Energy Materials Bioremediation, Microbial Physiology, eds. A.E. Torma, J.E. Wey, V.I. Lakshmanan, The Minerals, Metals and Materials Society of TMS, Warrendale, PA, 219-227.

46. Thompson, L. C. 1992. Developments in mine waste biotreatment processes. In: Emerging Process Technologies for a Cleaner Environment, ed. S. Chander, Society for Mining, Metallurgy and Exploration. Littleton, CO, 197-204.

47. Mudder, T.I. 1995. Times Ltd, Bozeman, Montana, personal comunication.

48. Scheeren, P.G.H., Koch, R.O., Buisman, C.J.N., Barnes, L.J. and Versteegh, J.H. 1991. New biological treatment plant for heavy metal contaminated groundwater. In: EMC 91: Non Ferrous Metallurgy - Present and Future. Elsevier, New York, 403-416.

49. Hammack, R.W., Dvorak, D.H. and Edenborn, H.M. 1993. The use of biogenic hydrogen sulfide to selectively recover copper and zinc from severely contaminated mine drainage. In: Biohydrometallurgical Technologies. I. Bioleaching Processes. Eds. A.E. Torma, J.E. Wey and V.I. Lakshmanan, Min. Met and Materials Soc of AIME, Warendale, PA. 631-640.

50. Brierley, J.A., Brierley, C.L. and Goyak, G.M. 1986. AMT-Bioclaim: A new wastewater treatment and metal recovery technology. In: Fundamental and Applied Biohydrometallurgy, eds. R.W. Lawrence, R.M.R. Branion and H.G. Ebner. Elsevier, Amsterdam, 291-304

51. Pett, R.J., MacKinnon, D.S and Lane, P.A. 1991. Natural wetlands fail to ameliorate acid mine drainage in the Fall. In: Proc.7th Annual Meeting of BIOMINET, ed. R.G.L. McCready, CANMET MSL91-001, 107-127.

52. Wildeman, T., Brodie, G. and Gusek, J. eds. 1993. Wetland Design for Mining Operations, Bitech Publishers, Richmond, B.C.

53. Gallinger, R., Gormely, L., Kistritz, R. and Sobolewski, A. 1991. Constructed wetland experiment for treating acid rock drainage at Bell Copper. Proc.15th Annual B.C. Reclamation Symposium. B.C. Technical and Research Committee on Reclamation, Victoria, B.C., 276-289.

54. Kalin, M. 1991. Ecological engineering applied to base metal metal mining wastes for decommisioning. In: Proc. 7th Annual Meeting of BIOMINET, ed. R.G.L. McCready, CANMET MSL91-001, 1-12.

55. Kalin, M. 1994. Boojum Research, Toronto, personal communication

56. Béchard, G., McCready, R.G.L., Koren, D.W. and Rajan, S. In press. Microbial treatment of acid mine drainage at Halifax International Airport. Proc. Sudbury 95, Conference on Mining and the Environment, Sudbury, Ontario, May 28-31, 1995.

57. Brierley, C.L. 1990. Metal immobilization using bacteria. In: Microbial Mineral Recovery, eds. H.L. Ehrlich and C.L. Brierley, McGraw-Hill Publishing Co., New York, 303-323.

58. Fyson, A., Kalin, M. and Smith, M.P. 1995. Arsenic and nickel removal by wetland sediments. In: Proc. 11th Annual Meeting of BIOMINET, eds. L. Lortie, W.D. Gould and S. Rajan, CANMET publication SP 95-1, Natural Resources Canada, 103-115.

59. Béchard, G. 1994. CANMET, Ottawa, personal communication.

60. Wasserluf, M. and Dutrizac, J.E. 1982. The chemistry, generation and treatment of thiosalts in milling effluents - a non-critical summary of CANMET investigations 1976-1982. CANMET Report 82-4E.

61. Brassinga, R.D., Fulford, G.D., McCready, R.G.L., Gould, W.D. and Beaudette, L. 1992. Removal of oxalate ions in aqeuous solution. Australian patent 626, 571.

62. Gould, W.D. and Koren D.W. 1995. Rotating biological contactors for the treatment of mining industry effluents. In: Proc. 11th Annual Meeting of BIOMINET, eds. L. Lortie, W.D. Gould and S. Rajan, CANMET publication SP 95-1, Natural Resources Canada, 11-21.

63. Jack, T.R. 1994. Applications of biotechnology in the fossil fuel sector. In: Proc. 10th Annual Meeting of BIOMINET, eds. W.D. Gould, L. Lortie and D. Rodrigue, CANMET SP94-1, 53-69.

64. McCready, R.G.L. 1993. Microbial capping of acid generating tailings. In: Biohydrometallurgical Technologies, Vol. II. Fossil Energy Materials Bioremediation, Microbial Physiology, eds. A.E. Torma, J.E. Wey, V.I. Lakshmanan, The Minerals, Metals and Materials Society of TMS, Warrendale, PA, 245-254.

65. Kleinmann, R.L.P. and Erikson, P.M. 1983. Control of acid mine drainage from coal refuse using anionic surfactants. USBM RI 8847.

66. Stichbury, M., Béchard, G., Lortie, L. And Gould, W.D. in press. Use of inhibitors to prevent acid mine drainage. Proc. Sudbury 95, Conference on Mining and the Environment, Sudbury, Ontario, May 28-31, 1995.

67. Bos. P and Kuenen, J.G. 1990. Microbial treatment of coal. In: Microbial Mineral Recovery, eds. H.L. Ehrlich and C.L. Brierley, McGraw-Hill Publishing Co., New York, 343-377.

68. Kempton, A.G., Moneib, M., McCready, R.G.L and Capes, C.E. 1980. Removal of pyrite from coal by conditioning with *Thiobacillus ferrooxidans* followed by oil agglomeration. Hydrometallurgy, 5, 117-125.

69. Jack, T.R. 1995. Novacor, Calgary, personal communication.

70. Dasu, B.N. and Sublette, K.L. 1989. Microbial removal of sulfur dioxide from a gas stream with net oxidation of sulfate. Applied Biochem. and Biotechnol., 200/21, 207-220.

71. Jack, T.R. 1992. M.O.R.E. to M.E.O.R.: an overview of microbially enhanced oil recovery. In: Proc. Int. Conf. on Microbial Enhanced Oil Recovery. Eds. E.T. Premuzic and A. Woodhead, Elsevier, N.Y.

72. Shaffer, N.R. 1994. Biotechnical materials. In: Industrial Minerals and Rocks, 6th edn., D.D. Carr, ed., Society for Mining, Metallurgy and Exploration, Littleton, CO, 157-169.

73. Rossi, G. and Ehrlich, H.L. 1990. Other bioleaching processes. In: Microbial Mineral Recovery, eds. H.L. Ehrlich and C.L. Brierley, McGraw-Hill Publishing Co., New York, 149-170.

74. Sand, W. 1987. Importance of hydrogen sulfide, thiosulfate, and methylmercaptan for growth of thiobacilli during simulation of concrete corrosion. Applied and Environmental Microbiology, 53 (7), 1645-1648.

75. Carlisle, D., Berry, W.L., Kaplan, I.R and Watterson, J.R. (eds). 1986. Mineral exploration: biological systems and organic matter. Rubey Voume V, Prentice-Hall, Englewood Cliffs, New Jersey, 465pp.

76. Lau, P.C.K., Drolet, M., Zanga, P., Holmes, D.S. 1993. Plasmid technology for biomining applications. In: Biohydrometallurgical Technologies, Vol. II. Fossil Energy Materials Bioremediation, Microbial Physiology, eds. A.E. Torma, J.E. Wey, V.I. Lakshmanan, The Minerals, Metals and Materials Society of TMS, Warrendale, PA, 635-644.

77. Goode, J. and Eljarbo, I. 1994. Biological oxidation of refractory gold ore - an economic evaluation. Addendum to Impurity Control and Disposal in Hydrometallurgical Processes. Proc. 24th Annual Hydrometallurgical Meeting of CIM. eds., B. Harris and E. Krause. Met Soc of CIM, Montreal, 339-352.

78. Carter, A.J. 1991. Economic comparison of the alternative methods for the recovery of gold from refractory gold ores. Proc. Colloquium on Bacterial Oxidation, South African Inst. Min. and Met., Johannesburg.

79. Litz, J.E., Carter, W., Kenney, C.W. 1990. Refractory gold treatment options - economics rule the way. Proc. Randol Gold Forum, Squaw Valley, NV., September, 39-44, 1990.

80. Sociedad Minera Pudahuel Limitada. 1981. A leach process applicable to combined minerals of oxides or sulfides of copper in piles. Republic of Chile Patent No. 32,025.

81. Bruynesteyn, A., Lawrence, R.W., Hackl, R.P. and Vizsolyi, A. 1986. Biological-acid leach process. U.S. Patent No. 4,571,387, Feb. 18, 1986.

82. Mudder, T.I and Whitlock, J.L. 1984. Strain of *Pseudomonas paucimobilis* var. *mudlock*. US Patent No. 4,461,834, July 24.

83. Mudder, T.I and Whitlock, J.L. 1984. Method for the biological removal of free and complex cyanides and thiocyanates from water. US Patent No. 4,440,644, April 3.

CHAPTER 3

ECONOMICS OF SELECTED BIOTECHNOLOGY PROCESSES

3.1 Introduction

Development of mineral resources is carried out with the goal to create wealth so that human welfare can be improved. However, development is often accompanied by significant adverse impacts on the environment. Degradation of the environment and misuse of natural resources will undermine the basic objective of sustainable improvement of human welfare. Steps must therefore be taken to favor the implementation of measures which ensure that development projects take both the environment and natural resources into account. It is clear that successful economic development depends on the rational exploitation of environmental resources and on minimizing the adverse impacts of development projects (1).

One of the difficulties in performing a cost-benefit analysis of biotechnology processes for mining resides in the small stock of cost data available. This report will have a positive impact concerning this aspect by bringing together and presenting an inventory of available costs. A second difficulty is the lack of knowledge on the environmental effect of these technologies at industrial scale and in the long term. However, costs and estimates of costs exist and qualitative assessments of impacts on the environment are available. This chapter will provide an economic analysis of the cost and benefit of the better documented biotechnological processes and the opportunities to put them to use. The focus will be on the comparison of the costs and benefits between biotechnology processes and more conventional ones.

This study is looking at the role of biotechnology in the Canadian mining industry and more specifically in the opportunities created by biotechnology. The notion of opportunity can be seen from at least two different point of view. The first is "application in Canada" by the mining sector. Are the known Canadian resources amenable to the process in sufficient quantity to justify research or an eventual use? Does the process answer a problem which we are facing or will face in Canada? The second is "application by Canadians". Canadians as individuals or as companies are active in mining around the world and benefit of a competitive advantage if R & D is done in Canada. This second category goes beyond the scope of this chapter, although the analyses clearly have pertinence. Our comments will mainly be for applications of biotechnology in Canada. International applications are in principle limitless.

The biotechnologies will be analyzed under the groupings: metal extraction processes and environmental processes. These two groupings correspond to the two major challenges facing the mining industry. Increasing power costs, lowering of domestic ore grade, and decreasing commodity price in real dollar terms require highly efficient and competitive extractive technologies. In addition, increased environmental demands require that these technologies be environmentally superior or that mitigation alternatives can be put forward. The following section will analyze biotechnology in this perspective.

3.2 Metal Extraction Processes

Biotechnology processes for metal extraction and those which contribute to extraction are currently principally associated with gold and copper mining. Processes that would address the extraction of zinc, nickel, cobalt and uranium have not been competitive based on actual prices of these metals and the level of technology development. Unless markets experience some imbalance relative to one of these metals, a price change important enough to change this situation is not foreseen.

3.2.1 Gold mining

Gold production in the 1990's has been stable in the range of 2,200-2,400 tonnes per year. The price outlook does not point towards change. Gold has been trading in a narrow margin and should continue to do so for some time. Gold Fields Mineral Services reported another primary gold supply deficit in 1994 (2), making a downside change of gold price improbable. To increase profit margin in their domestic operations, Canadian producers will therefore have to act on the cost side of the equation.

Available cost data for biotechnological processing of gold are presented in Table 3.1, with feed material in the form of concentrate, ore or low grade ore/waste. The data are site specific but valuable in showing the magnitude of cost and the applicability of the processes.

Table 3.1. Cost data for gold biotechnology

Mining Project	Application	Capacity	Start Up Date	Capital Cost Million US$	Operating Cost US$/t	Refs
Harbour Lights, Australia	Concentrate	40 tpd	1992	2.4	?	3
Wiluna, Australia	Concentrate	115 tpd	1993	5.6	61-72	3,4,5
Sansu, Ghana	Concentrate	720 tpd	1994	25	13	3
Youanmi, Australia	Concentrate	120 tpd	1994	3.9	38-45	4,5,6
Newmont-Nevada, USA	Low grade ore		forthcoming		4-6	7,8
Mt. Leyshon, Australia	Copper leach from ore	500,000 tpa	1992		300-400 US$ per oz Au	9

3.2.1.1 STR biooxidation of refractory gold concentrate

The technology of stirred tank reactor (STR) biooxidation applies to concentrates of gold ore that are refractory to conventional cyanidation. The first four projects shown in Table 3.1, Harbour Lights, Wiluna, Sansu, and Youanmi are greenfield projects of this type that have been put into production since 1992. There is a wide range of total capital cost and capacity of plants. A calculation of the ratio of capital cost by capacity from the unit capital cost would show that some benefit of economy of scale is available concerning the three first plants, based on Biomin S.A. technology. The Youanmi project of BacTech technology has a very low unit capital cost but the uniqueness of this plant does not

permit us to isolate site specific factors from technology factors that could affect costs. In general, however, we can say that process costs and economic efficiency are sensitive to gold grade and the amount of sulfur to be oxidized.

The unit operating costs refer to US$ per tonne of concentrate. They are very different from one another for the three plants for which we have information. All three claim a gold recovery in the order of 90 to 94%. However, their main differentiating factor is sulfur content and the level it needs to be oxidized. At Wiluna, for example, a much higher degree of oxidation is required (90% oxidation) compared with at Youanmi (30%). Another way to present operating cost is by cost per kg of gold produced. Rough calculations based on the available information would put Wiluna and Youanmi in the same order of magnitude at around US$800/kg. In comparison, costs per kg gold at Sansu are probably half this cost. This shows again that gains by economy of scale are possible but one has to remember that this ratio is also dependent on ore grade.

Biooxidation processes can be compared to conventional alternatives such as roasting and pressure leaching. Roasting of flotation concentrates has conventionally been used to break-down sulfide minerals, exposing the gold for subsequent cyanide leaching. Roasting is also applicable to ores containing organic carbon, mitigating the preg-robbing characteristics of the ore. However, roasting flotation concentrates and ores can be capital and operating cost intensive. If arsenic is present, a two-stage roaster is often required to remove arsenic as arsenic trioxide and then degrade the remaining sulfide. Gas scrubbers are essential to capture sulfur dioxide and arsenic trioxide emissions. Two-stage roasters and emissions control devices greatly increase capital costs and if all costs relative to emissions are internalized by the company, operating cost are also increased.

Autoclave processing involves the breakdown of sulfide minerals using steam and oxygen injection under pressure, exposing the gold for cyanide extraction. While pressure autoclave treatment typically results in good recoveries, this process does not destroy the preg-robbing character of the ore when carbonaceous material is present. Pressure autoclaves are capital intensive because of their advanced materials of construction and need for an oxygen plant. The high level of operator training and skill necessary and increased safety requirements to handle the high pressures and temperatures increase operating costs of this process.

Biooxidation plants have advantages and disadvantages that influence their economic attractiveness. Advantages include the absence of noxious off-gases or toxic effluents, ease of operating, tolerance to a wide range of sulfur grade feed and the production of a stable iron/arsenic residue. However, they are sensitive to water quality particularly with respect to cyanide and thiocyanate, can entail sizable power and neutralization costs, and require lengthy residence time measured in days.

Recent studies (10, 11) have shown that gains in economy of scale are possible with conventional processes and that smaller volumes can be treated economically by biooxidation. Both studies indicate that a refractory gold operation smaller than 2,000 tpd of concentrate would have a higher NPV if a biotechnology process is employed. This shows that biotechnology has a niche in gold production. It

is economically preferable for smaller projects, assuming that recovery from all the processes are similar. Many Canadian refractory gold deposit are small in size and could be exploited using a process adapted to small capacity and which is simple to operate. The cross-over point between technologies is based on inferred costs since no biooxidation plants have been built for a throughput larger than 720 tpd. As information accumulates, the cross-over point will be pinpointed with more precision. It should be noted that factors are at work displacing the cross-over point, such as environmental constraints, safety, and ease of use. As producers are asked to reduce discharge, technologies such as biotechnologies are favored. In addition it is stated (11) that a higher return has been demanded from biotechnology processes because of the inherent risks associated with unproven industrial size projects. This hurdle is disappearing as biooxidation plants are built and operating data become available.

3.2.1.2 STR biooxidation of refractory gold mill products

The process analyzed in the previous section could also be used to treat sulfide-gold concentrates of tailings from cyanide or flotation mills. In some cases, such tailings have a sizable amount of refractory gold present and could be concentrated by further flotation processing. The actual plant operating data now available can be used to provide a firm economic basis to evaluate projects that have been believed to be marginal. To date, there are no operations that treat concentrates of tails but with the information from operational industrial size plants of STR biooxidation, it is possible to define minimum concentrate feed. As a general rule of thumb, for a process to be economic, the ratio of the gold grade, expressed in g/t, over the amount of sulfur that needs to be oxidized, expressed in %, should be 0.7 or more (4). Using this ratio, sources can be targeted. Based on the Canadian geological context, such sources would likely be small in tonnage. Since the data provided in section 3.2.1.1 shows that STR biooxidation is the best available technology for small refractory gold operations, there is a potential to be used.

Canadian opportunities are exemplified by the pilot plant operated at the Dickenson Mine (12). At this site, sulfides are concentrated from the cyanidation tailings prior to disposal. This sulfide concentrate contains refractory gold and was previously treated in a roaster on site. Concentrates are now stockpiled, being uneconomical to ship to an alternative facility for treatment, and would in principle be a candidate for biotechnology treatment. Another Canadian example of the opportunity of biooxidation to recover gold from tailings was the flotation tailings produced at the Equity Silver operation in B.C. This operation has closed and the opportunity is now lost, although biooxidation treatment was demonstrated successfully at pilot scale (13). Operating mines could, therefore, add a biooxidation circuit to the mill.

The economical remobilization and reprocessing of tailings also could provide a benefit by creating the opportunity to improve the environmental disposal of mining residues. The reprocessed tailings, reduced in sulfur and metal content, could be stored in locations that were not previously available, such as a worked-out open pit, to reduce their environmental liability. Benefits from a break-even venture could still be attractive if residue storage is improved.

3.2.1.3 Treatment of refractory gold in low grade heaps

Bio-heap leaching can generally be considered when the ore is low grade and economics cannot sustain the cost of making a concentrate, or the mineralogy is such that the ore cannot be concentrated, or the economics do not support conventional treatment. However, low grade gold ores that are refractory require some oxidative pretreatment before they can be conventionally leached. A biotechnology process developed by Newmont Mining in Nevada prepares potential ore for gold recovery by biotechnological heap treatment. The costs given in Table 3.1 for the project Newmont-Nevada refer to this process. Waste material as low as 1 g/t Au are now being test-heap leached on a significant scale.

Benefits of this process are converting possible waste to reserves, controlling acid and metals leached from ore in solution, and utilizing recirculated biooxidation solution for the agglomeration and inoculation of ore coming into the process. It provides the opportunity to make an efficient use of the resources by extracting a maximum value from disturbed host rock. Since iron-arsenic residues are generated, costs for their safe disposal will be incurred, although in many cases, residue disposal could be incorporated into the major process (roasting or pressure oxidation) flowsheet without significant extra cost.

There is no alternative technology that can economically recover refractory gold from such low grade material. Effect on reserves and resources at operations where infrastructure are present could be important because 70% recovery on waste material has been experienced (8).

Although this process is more likely to be used on low grade material from an existing operation utilizing a primary method of ore treatment, the emergence of this process also makes an opportunity to treat a low grade deposit in a greenfield operation. However, in this case, gold values would need to also support the mining costs. Marginal refractory gold deposits would be offered an alternative.

3.2.1.4 Removal of contaminants from gold ores

At the Mt. Leyshon operation in Queensland, Australia, gold ore containing copper values were stockpiled because of extraction problems related to cyanide consumption by the copper mineralization. A biotechnology process was developed to extract copper from ore prior to leaching the gold, thus converting waste material to ore. The process recovers copper and helps to control natural acid and metals leaching from the discarded ore. Costs are presented in Table 3.1 under the project name Mt. Leyshon. The information is not detailed but gold can be produced at a profit from previously waste material making the entire resource extraction process more efficient. Revenues from copper recovery are also realized.

There is no other technology that could produce economically viable at Mt. Leyshon. Since copper and other cyanicide contamination of gold ores is a common occurrence, this experience is likely to be adopted at other operations where cyanide consumption costs are prohibitive. It expands the spread between costs and revenues in cases where losses of cyanide are due to sulfides, by reducing the cyanide consumption while simultaneously providing extra revenue with copper.

3.2.2 Copper extraction

Copper markets and price are currently greatly influenced by the mining production of Chile. Copper prices will remain firm at actual levels until 1996-1997 when over-capacity and a more flat production cost curve will bring price down until probably 2002 in the opinion of CODELCO, the state copper mining company of Chile (14). This indicates that emerging processes to produce copper can not rely on increasing prices and need to be economic with current values.

The single largest application of biotechnology in the mining industry has been the bioleaching of low-grade, sulfidic copper ores in dump leaching. Although the secondary copper sulfides, chalcocite and covellite, are more readily leached, even the relatively refractory chalcopyrite has been a very significant source of the metal by this leaching method. Currently, thin-layer bioleaching of ores containing chalcocite and other readily oxidized sulfide minerals and copper oxide minerals is increasing in popularity as a primary treatment method for copper recovery. To date, STR biooxidation of copper ores and concentrates has not progressed beyond the laboratory or small pilot scale.

The cost information presented in Table 3.2 cannot be readily compared to each other because each data set does not include exactly all the same components of mining. However, they have in common that they produce copper directly without smelting, thereby avoiding the release of SO_2. The competing and conventional technology involves grinding and flotation of the ore to produce concentrate, followed by smelting. The environmental benefit of avoiding the conventional processing route can be seen to be significant if all smelter environmental costs are accounted for. Some discharge from smelters is permitted, but if we as a society choose to internalize all costs, we can use the calculations published by BC Hydro (15) to place a value (cost) on SO_2 emissions. These calculations include all social impacts related to emissions and are used by the utility in its analysis of purchasing power. Emission cost for SO_2 is evaluated at $4.90/kg with the health impact providing the bulk of the cost. If such a cost is included in process comparisons, the advantages of biohydrometallurgy can become very attractive.

Table 3.2. Cost data concerning copper

Mining Project	Ore Type	Process Type	Capacity tonnes Cu/y	Capital Cost Millions US$	Operating Cost US$/lb Cu	Refs.
McLeese Lake, BC	chalcopyrite	dump leach	5,000	11.2	0.70	16
Quebrada Blanca, Chile	chalcocite	thin layer leach	75,000	342	< 0.50	17
STR biox of concentrate	chalcopyrite	STR biox	33,000	71.4	?	18,19

3.2.2.1 Dump leaching

It was estimated in 1982 that over 10% of the US copper production came from dump leaching (20). It is probable that this significant level of production has been maintained or exceeded since that time. This "hydrometallurgical revolution" has been claimed to be largely responsible for reviving the US copper industry in an era of low copper prices, diminishing grades, and tightening environmental restriction (21). Despite increasing popularity throughout the copper producing countries of the world, copper dump leaching is practiced at only one mining operation in Canada at the Gibraltar mine in B.C. This can be largely explained by three factors: the main copper mineral is chalcopyrite, the climate of Canada is cold and sulfuric acid costs are high due to the predominantly acid consuming nature of the host rocks of potential dumps.

The McLeese Lake deposit of Gibraltar Mines is producing copper by leaching chalcopyrite from its waste dumps in combination with solvent extraction and electrowinning (SX-EW). The leached material would have otherwise been classified as waste. It is a large scale scavenging operation. Costs related to the Gibraltar operation are given in Table 3.2. Capital cost refers only to the construction of the SX-EW plant and the piping related to leaching. Operating costs include only the leaching related costs and processing to copper cathodes. Design steps are required for the sprinkling devices because of the cold climate and the extraction and electrowinning facilities must be enclosed (22). Leaching enhances the economics of the existing McLeese Lake operation since supplemental high quality copper production can be achieved at a profit. Mining and infrastructure costs are absorbed by the conventional mining and milling operation.

Benefits of the process are increased efficiency of the mining operation by recuperating a greater amount of metal and the avoidance of SO_2 smelting emissions because of electrowinning. The cost side of the analysis has to include the environmental costs related to rehabilitation at closure. When the leaching operation ceases to produce sub-economic solution grades, the dumps will continue to generate contaminated effluents (ARD) that will need to be mitigated. This could prove to be difficult and expensive.

Application of dump leaching would be for open pit mines that generate important tonnage of waste rock at low grade. The Gibraltar Mines McLeese Lake experience has proven that climate is not an impediment for leaching, since the exothermic reactions taking place maintain satisfactory internal dump temperatures during the cold winter months Susceptible geological targets are porphyry copper deposits. These deposits produce large enough copper dumps to warrant consideration of dump leaching. Changes in copper reserves could come from the inclusion of dumps and marginal deposits in the resource base. This would primarily affect B.C.'s potential.

3.2.2.2 Thin layer leaching

Thin layer leaching of ore applies mainly to copper ores containing chalcocite and other readily oxidizable/leachable minerals. Leaching is done on prepared heaps and is not an add-on to a conventional process but the main production approach. This could not be applied to important tonnage in the Canadian geological context but is the base of very large Canadian investments

overseas. Insight into the potential of biotechnology can be gained by analyzing this production method. Large tonnage operations have been recently commissioned in Chile, with others planned for startup in he relatively near future. An example of this process used in this analysis is at Quebrada Blanca, operated by a Canadian firm. Costs of the operation are given in Table 3.2. The capital cost figure represent the total investment for the mine. It includes development and infrastructure. The operating cost includes not only leaching and SX-EW but also the mining of the ore. Taking all costs together shows that copper can be produced for less than US$0.80/lb. In the context of Chile this process clearly demonstrates economic benefits.

3.2.2.3 STR biooxidation of copper concentrate

A STR bioleaching approach can also be used for copper concentrates, with leached copper recovered by SX-EW. However this application has not been applied at commercial scale. Conventional high-grade chalcopyrite concentrates as well as lower-grade bulk concentrates produced to maximize recovery could provide feed to a biooxidation plant. Laboratory evaluations indicate recoveries from chalcopyrite can be low (40-70%) although recovery from chalcocite-type concentrates would be high. High copper recoveries (>90%) from chalcopyrite concentrates have been demonstrated in a catalyzed bioleach (19) and the recent success of biooxidation of refractory gold concentrates has renewed interest in developing other high-recovery systems (6). The benefits of STR biooxidation would include: non-emission of SO_2, value-added in the producing country, and the elimination of transportation to overseas smelters for some areas of the country. On the cost side of the analysis are the risks of scaling up a pilot concept, potentially lower copper recoveries, and the possibility of lower precious metal recoveries/credit.

The estimated capital cost for catalyzed bioleaching is presented in Table 3.2 and is in 1985 dollars transformed with a 0.7 exchange rate in US$. This cost applies only for the plant and does not include all the costs associated with producing the feed concentrate. Costs elements from the existing gold STR biooxidation plant described in 3.2.1.1 can be used to some extent to estimate the operating cost of oxidizing copper sulfides in tanks. For example, a 25% Cu and 30% sulfur concentrate would need to be oxidized at 100%, followed by SX-EW. This can be estimated to cost US$0.25 to 0.30 per lb Cu. To this value a unit capital cost must be added for a probable US$0.40 to 0.45. Relatively large amounts of sulfur in relation to metal value need to be oxidized. This makes this type of process relatively costly. These cost estimates can be readily compare to smelting. Current smelting costs are typically around US$0.25 per lb Cu to which transport must be added. With these estimates, the STR bioleaching process could be attractive when transport cost are excessive. However, the bioleaching costs are inferred and should be regarded as indicative only. It is premature to comment if this process could have an effect on mineral reserves in Canada.

3.2.3 Cobalt, uranium, zinc and nickel

Similar speculation concerning Co, U, Zn and Ni can be carried out on the model used in the previous section for copper. It can also be shown that the level of price of these commodities are relatively insufficient to expect an economical biotechnological process in the short run except maybe for cobalt. The price of cobalt could increase since this metal qualifies in all respects as a strategic mineral. It has

a rising demand profile, is critical to the technology based industries, and is mined in a handful of politically sensitive countries (23). Main available reserves are in Zaire, Zambia and Cuba. The potential price change is great if one believes that Zaire, the world's leading producer, could politically implode.

Uranium is a metal whose price has been falling for 14 years (24). Demand is larger than supply and inventories are decreasing. However, the existence of high grade deposits in Saskatchewan and the possibility that military uranium could be used as fuel, counteract any possibility of increase in price. Uranium has seen some production by bioleaching in Canada but future potential is small.

Zinc is oversupplied and the lack of integration between mining entities and smelters will help maintain low prices for some time (23). Nickel price is CIS dependent. Because it is a source of hard currency for the former USSR, the market will need to establish its equilibrium through the demand side. Also the development and the discovery in Canada of large nickel deposits does not favor the emergence of alternative technology.

Extraction of non-ferrous, non-precious metals by biotechnology, as demonstrated by the copper case, will require important economic change in one of the components of production and/or environmental cost. This could be an increase in price (not likely), an increase in cost of conventional treatment, increased penalties for SO_2 emitting processes, a decrease in STR bioleaching costs, or a demonstrated productivity gain from size or another source. The commercial development of industrial plants for gold has, however, opened an avenue that needs to be re-evaluated.

3.3 Environmental Processes

In historical terms, there has not been much conflict between competing land uses. Mining has usually been considered the "highest and best" use of the land (25). That this has been the case was natural because for most mines the value of the orebody has greatly exceeded the market value of the land on which it is located. It is only with the realization that wide ranging spatial externality effects occur with mining, and that the value of other uses for land can now be very significant, that conflicts have arisen. This has provoked an intense demand for processes that reduce externalities to make mineral exploitation more acceptable both from a regulatory and public viewpoint. An important aspect towards this reduction is the control of emissions and, in particular, effluents from mining operations.

Large amounts of money are spent by companies to minimize environmental effects and by public authorities to mitigate urgent problems. A recent informal survey has indicated that company expenses for environmental control are in excess of $Cdn 10.7 million per year for only 12 mine sites out of the more than 100 sites in Canada (26). In a broader industrial context and looking at the potential role of biotechnology, the estimated demand for bioremediation in Canada will be between 25 and 50 million dollars per year by the year 2000 (27). These circumstances make a favorable climate for processes directed at improving the quality of emissions and effluents.

This section will look at bio-environmental processes for the mining sector under three headings: (a) cyanide destruction, (b) metal removal, and (c) other applications. The two first headings, cyanide destruction and metal removal, already have representative biotechnology processes that have been used at industrial scale. In the third group, we will briefly analyze processes that are not yet applied commercially. Many of the technologies that will be analyzed would also apply for closure/remediation of mining sites.

3.3.1 Cyanide destruction

Cyanide is widely used in the mining industry as a leaching agent for gold and as a reagent in flotation circuits. Its discharge from gold mills, heap leach operations, and processing plants is rigorously controlled to prevent impact on aquatic life in the receiving environment both from simple and complex cyanide species and from related compounds such as thiocyanate and ammonia. Permit discharge concentrations are very low in all jurisdictions in North America and most other parts of the world. Destruction of cyanide and related compounds can be readily achieved, though sometimes at significant cost, by oxidation processes. To reduce costs of achieving the very low permitted discharge levels, plants often rely on natural degradation in the tailings pond or other impoundment for final polishing following chemical destruction.

3.3.1.1 Cyanide destruction in gold mill effluents

This section will compare one biotechnology process of cyanide destruction, the Homestake process, with the two principal chemical destruction processes. All three process have been used at industrial scale, although to date, biotechnological cyanide destruction is used at only one plant in South Dakota. Cost data are presented in Table 3.3 and performance information is also available.

The Homestake process is biotechnology based and has been in use at a commercial scale at the Lead mining operation in South Dakota since 1985. This process has two exclusive properties: (i) it produces effluent that can be discharged directly into the receiving environment without any further processing steps;, and (ii) its total operating cost remains quasi-constant for CN concentration between 0 to 50 mg/l. The non-sensitivity of total operating cost to CN loading in solution produces an unusual effect. The unit operating cost per tonne of CN is high because the solution treated at Lead is dilute (typically 6 mg/L) but the unit operating cost expressed in $ per tonne of ore is small.

The two chemical treatment processes given for comparison are the Inco SO_2-Air and the Hydrogen Peroxide processes. They are the most widely used processes in Canada for cyanide destruction. The costs given in Table 3.3 are presented as ranges to reflect different process back-end needs, such as tailings, clarifier and/or polishing pond(s). The various process flowsheet possibilities result in a divergence of capital and operating costs.

Comparison of biotechnological processing with conventional chemical treatment using the cost data presented in Table 3.3 is made more difficult since the Homestake process has only been used at one site while the others have been widely used and extensive statistics can be consulted. The Homestake is the only process that is temperature sensitive. Whereas at Lead, the mixing of underground mine water

with the process feed ensures an essentially constant and satisfactory year-round temperature for microbiological activity. Canadian use might require the heating of solutions using waste heat in winter. The Inco-SO_2 process can treat effectively a slurry or solution, whereas the two others processes are only applicable for solutions. The resulting effluent from the Inco-SO_2 and the Hydrogen Peroxide processes often still contain species such as ammonia that need to be safely disposed for a cost. In contrast to the chemical methods, the Homestake process effectively degrades all forms of cyanide, including a portion of the stable iron-complexed cyanides. Metals are removed in an easily contained sludge. Transport of reagents and availability of SO_2 can also influence the choice of a chemical treatment process.

The capital cost of the Homestake process is much higher than for the competing processes. However, notwithstanding the fact that capacity is twice that of the others in the available examples presented in Table 3.3, two more factor must be considered. The plant in Lead, because it was the first of its kind, was over designed (28). Features included at the time are now judged excessive. In addition, it is suspected that some costs that have been included could also be labelled R & D.

The fact that there is only one plant operating with the Homestake process indicates that there is either a resistance to the technology or that its benefits (higher quality effluent) is not currently a need. With the trend toward more stringent regulations, the benefits will take on greater significance and process costs will need to be compared at equivalent discharge quality. Resistance to a new or unique process decreases with the growing number of applications. It is understood that a biotechnology cyanide destruction plant is being constructed in New Zealand (28). As further plants are constructed, it will be easier to define the comparative advantages of the Homestake process in relation to the conventional processing routes and to determine the niche for this process.

Table 3.3. Comparative cost data for cyanide destruction in effluents

Process	Capacity t ore/day	Capital Cost Millions US$	Operating Cost US$/t CN	US$/m³ soln	US$/t ore	Refs
Homestake Biodegradation	6,000	10.0	15,000	0.11	0.35	28,29
Inco SO_2-air	3,000	2.3 - 2.8	3,800-4,900	0.10-0.60	0.18-0.90	30
Peroxide	3,000	2.3 - 2.9	10,300-11,400	0.25-0.28	0.50-0.55	30

3.3.1.2 Cyanide heap leach detoxification

The technology of gold heap leach detoxification of cyanide is not of immediate concern, since this type of process has been little used in Canada. However, in the event that there might be some leaching in the future, on ore or tailings, detoxification will be an important concern. Some experts believe that cyanide detoxification is, in fact, a non issue (28) and should take second place to the more significant problems of the mitigation of heavy metals in the effluent in the short term and ARD in the longer term.

Detoxification using biotechnology has been practiced commercially as an alternative to conventional chemical treatment using peroxide. Costs of biodegradation have been given as US$0.10-0.15 per t ore (31) which can be compared with peroxide costs of $0.30-0.50 per t ore (28). Cyanide detoxification can also be simply done at lower cost by exposing cyanide to natural degradation by recirculating dump solution and evaporation. The addition of phosphate to recirculating solutions can assist in promoting the growth of naturally occurring cyanide degrading microorganisms within the spent ore pile.

3.3.2 Metal removal

The removal of heavy metals from solution is a major concern for the industry and is an important cost center. In Canada, metal contamination of drainages and seeps emanating from waste management units resulting from the generation of acid rock drainage (ARD) is a particularly significant problem at many mine sites.

Reference to Chapter 2 will show that several biotechnology approaches have been developed and evaluated for metal removal. However, in our analysis, the two biotechnology approaches which have achieved commercial application will be considered, namely active sulfate reduction and wetlands. In addition, other related processes have been included for which some cost data estimates were available. They will be compared to the very widely used lime treatment method for which sludge disposal costs have been included. Data are presented in Table 3.4. Other biotechnology possibilities will be briefly discussed in Section 3.3.3.

Lime treatment relies on simple and standard engineering, is well proven and has been adapted to all flow sizes and contaminant loadings. Active sulfate reduction and wetlands will not be directly compared because it is not felt that they offer competitive alternatives to each other. In our view, active sulfate reduction, using highly controlled engineered systems is applicable to higher flows and loadings. Wetlands are passive systems and are applicable to lower flows and loadings. Some overlap in applicability is likely but the data presented in Table 3.4 does not provide sufficient quantity and quality to support a meaningful analysis

3.3.2.1 Active sulfate reduction

Sulfate reduction is a process in which sulfate-reducing bacteria reduce sulfate to sulfide under anaerobic conditions. Metals are removed by precipitation as sulfides. Active sulfate reduction refers to processes in which reactions are optimized by controlling bacterial growth and activity in in-plant engineered reactor systems. In contrast, sulfate reduction which takes place in wetlands and ecologically engineered systems relies on natural decomposition processes to provide nutrients and is termed passive.

Three examples of active sulfate reduction are given in Table 3.4. For Case 1, active sulfate reduction is being used at industrial scale at the Budelco plant in the Netherlands. Case 2 cost estimates are conceptual and based on a projection made by the Budelco operators for a different solution loading. The third example is the BioSulfide process, which is has been proven at the laboratory stage.

Some advantages of the active sulfate reduction process are high metal removal, sulfate removal to below 200 mg/l and no solid waste/sludge for disposal. The limitations include the supply and cost of suitable substrate/electron donor for the bacteria, and concerns that the process is too capital intensive for small scale applications. Effluent water from the process is at a neutral pH. Similar comments apply to the BioSulfide process. However, in the absence of large scale operating data, process performance and economics would need to be confirmed.

Table 3.4. Metal removal cost data

Process	Capacity m^3/day	Solution mg/L	Capital Cost million US$	Operating Cost US$/m3	Operating Cost US$/kg metal	Operating Cost US$/kg SO4 or acidity *	Refs
Active sulfate reduction (Case 1)	5,000	metal 150 sulfate 500	7.5	0.11	0.75	0.038	32
Active sulfate reduction (Case 2)	5,000	metal 9,000 sulfate 30,000	30	3.6	0.40	0.014	32
BioSulfide Process (active SO_4 reduction)	15,000	metal 100 sulfate 1,300	?	0.04	0.32	0.05	33
Lime (conventional Case 1)	4650	metal acidity 500	0.9	0.19		0.38	34
Lime (conventional Case 2)	4650	metal acidity 5,000	1.1	0.88		0.18	34
Lime (high density Case 1)	4650	metal acidity 5,000	1.4	0.20		0.39	34
Lime (high density Case 2)	4650	metal acidity 5,000	1.7	0.85		0.17	34
Lime (conventional Case 3)	7,900	metal 1,000 sulfate 8,500	3.4	0.60	0.60	0.07	35,36
Wetlands (1)	5,500	metal 270 sulfate ?	2.8	0.06	0.24	?	36
Wetlands (2)	7,900	metal 1,000 sulfate 8,500	26.6	0.10	0.10	0.01	35,36
In-pit sulfate reduction	360	metal 750 sulfate 4,000	1.7	0.68		0.17	37
Biological polishing (Zinc removal)	900	metal 10-15 Zn acidity 24	0.5	0.05	3.50	2.19	38

* concentrations of SO_4 and acidity assumed to be generally equivalent

The competing technology is lime treatment. Wetlands can also be seen as competitive in some class of problems and complementary for other classes. Comparing cost figure between cases of lime treatment with equivalent flow and solution loading with active sulfate reduction shows that lime scenarios have both lower capital and operating costs. However, the lime process generates sludges that must be stored in a way that they are not leached of their metal content. It can also be noted that with the active sulfate reduction processes, sulfides of copper, zinc and perhaps other metals can be selectively precipitated and sold for revenue. In the case of the hypothetical project, Case 2, revenue from metal sales, assuming a net smelter return of 50%, would be around US$1.00 per m^3 of solution. These two points alone make biotechnology and conventional lime treatment more equivalent concerning operating costs than it appears at first reading.

Capital costs are very different with a strong advantage to lime treatment. This could be expected from a matured process with relatively "standard" engineering. Effluent quality value is not pertinent when minimal standards are currently met. This could prove different if more stringent standards are imposed in the future.

3.3.2.2 Wetlands

Natural wetland ecosystems account for 6% of the global land area and are among the most threatened of all environmental resources. Social inefficiency in wetland use is connected to the fact that wetlands are multifunctional resources and that some multiple uses conflict with each other (39). For example, the accumulation of heavy metals and the sustainment of wild life are not compatible. To gain benefit from wetlands , they need to be located in relation to need. This has led to the concept and trials in engineering wetlands. A typical man-made passive treatment-system can mimic a natural wetland by employing the same geochemical principles (36).

The most evident use for wetlands is for small flows at low loading but the concept could apply to other circumstances. It should be noted that wetlands are not very effective in winter and that eventually, the removal of metals accumulated in the wetland sediments will be required. The use of modified natural wetlands could prove problematic in the future for conservation reasons.

Table 3.4 presents estimates of costs for two cases of wetlands with different contaminant loading. These cases are conceptual. Capital costs are very different since the wetlands must be sized in relation to assimilative capacity. In this regard, solution flow rate and loading are influential factors. Wetlands can be costed on the basis of area ($\$/m^2$). However, the range of costs quoted in the literature (40) is very large ($\$1.19$ to $139.89/m^2$). For lime treatment, capital cost is highly predictable. For wetlands, local factors can have a large influence on construction costs. The difference between wetlands and lime treatment is the higher capital cost and lower operating cost for wetlands. With this type of difference in money outflow, comparative analysis of costs over a long time span (say 30 years) is highly influenced by the discount and inflation rates used. The escalation of costs by using a particular inflation rate could tip the balance between the two options. Cost escalation should not be ignored but non-inflated scenarios should also be presented. The application of blanket inflation rates is not acceptable since different cost components do not inflate in the same way. In our analysis, therefore, published estimates of costs (36) have been deflated to allow better comparison.

The benefits of wetlands reside in their passive nature. Passive systems present a 'friendly' approach and one which regulators will probably favour in the future in contrast to the 'collect and treat' option. The disbenefit is the risk associated with a process which has yet to be tested in the long term with respect to cost and efficiency. In contrast, the lime plant option is not affected by such long term questions. For wetlands, long term maintenance is also untested and the fate and requirements for heavy metal sludge removal and its disposal has to be addressed.

3.3.2.3 Other metal removal processes

In-pit sulfate reduction would utilize a flooded open pit as a reactor where sulfate is bio-transformed to sulfide. This concept has not been tested under field conditions. The costs given in Table 3.4 should only be considered indicative and include secondary lime treatment following the sulfate reduction stage. The researchers associated with this process are uncertain if this treatment will be necessary.

Estimated costs of zinc removal by biological polishing are also given by Table 3.4. This and related processes has been evaluated at several mine sites in Canada. The costs at this point can be seen as site specific because of the novelty of the approach. To be viable in the long run, ecological engineering approaches for metal removal have to be integrated in the local ecology. This integration varies from site to site if the construction of artificial structures for water management are to be minimized. Another example would see the use of cattails to remove metals and nitrogen from effluents. Preliminary calculations show that the capital required to construct the cattail structures required to remove of a tonne of nitrogen per year would be in the order of $300,000, not including any required water management costs.

It is emerging that the application of processes widely defined as ecological engineering have an application in mining and would have a preferred domain of application for smaller flow and low contaminant loading. Lack of longer-term field data does not permit a clear estimate of the size, costs and performance.

3.3.3 Other environmental applications

Under this wide category we include the processes described in Chapter 2 which have very limited information on costs and on experience at the industrial scale. Some of these have pilot scale results and many have only been proven at the laboratory scale or are conceptual. Therefore, limited information is available on the supply side of the equation concerning biotechnology applied to mining environmental problems others than those treated in the previous two sections. However, many environmental problems for which there is a sizable market and for which existing technology is inadequate should be targeted. The analysis would then be better suited to proceed from the demand side for biotechnology process development.

In addition to cyanide destruction and metals removal already discussed, areas that could benefit from biotechnology include: biosorption of heavy metals, uranium and radionuclides; selenite and selenate reduction; thiosalt treatment; oxalate degradation; nitrate and ammonia removal; and degradation of organics. In some cases, costs for processes have been estimated. For example a detailed comparison of costs was compiled for thiosalt treatment in 1982 (41). Lack of details for the components of these costs and the significant time that has passed since the study makes a proper analysis difficult. Such numbers have, therefore, been omitted in this report.

3.4 Site Closure/Remediation

Site closure/remediation in mining does not call for a specific method or process. Classical methods to deal with mine waste and mill tailings include: to submerge; to cover dry or wet; or to collect and treat with lime. Choice is dictated by field conditions and the nature of problem.

Biotechnology processes can make a contribution for site closure/remediation. The majority of the processes described in this environmental section are applicable to a lesser or greater extent. Those processes that are passive, benefit by the advantages stressed in the section on wetlands. These processes offer the promise that walk-away solutions could one day be achieved.

3.5 References

1. Dixon, J.A., Carpenter, R.A., Fallon, L.A., Sherman, P.B. and Manopimoke, S. 1988. Economic analysis of the environmental impacts of development projects. Earthscan Publishers.
2. Gold Fields Mineral Services Ltd. 1994. Gold 1994. Report by Gold Fields Mineral Services Ltd, London.
3. Marais, H. 1994. Genmin, Johannesburg, South Africa, personal communication
4. Briggs A. 1995, Signet Technology Inc, Englewood, CO, personal communication.
5. Brierley, C.L. 1995. Bacterial oxidation: revolutionizing the gold industry. Proc. Australian Gold Conference, Kalgoorlie, Western Australia, March 15-16, 11pp.
6. McCrae, P. 1995. BacTech, Perth, Australia, personal communication.
7. Horton, N. 1994. Precious and playing hard to get: baby bio grows up - Newmont Gold. World Mining Equipment, 18(11):11-14 and 37-38.
8. Brierley, J.A. 1995. Newmont Exploration Ltd, Metallurgical Services, personal communication.
9. Ellis, S.J. 1994. Bacterial copper heap leach followed by heap leach recovery of gold at Mt. Leyshon gold mine. In: Biomine 94, Chapter 8, Australian Mineral Foundation, Glenside, South Australia.
10. Carter, A.J. 1991. Economic comparison of the alternative methods for the recovery of gold from refractory gold ores. Proc. Colloquium on Bacterial Oxidation, South African Inst. Min. and Met., Johannesburg
11. Goode, J. and Eljarbo, I. 1994. Biological oxidation of refractory gold ore - an economic evaluation. Addendum to Impurity Control and Disposal in Hydrometallurgical Processes. Proc. 24th Annual Hydrometallurgical Meeting of CIM. eds., B. Harris and E. Krause. Met Soc of CIM, Montreal, 339-352.
12. Chapman, J.T., Marchant, P.B., Lawrence, R.W., and Knopp, R., Biooxidation of a high-arsenic sulphide concentrate: a pilot study. FEMS Microbiology Reviews 11, 243-252 (1993).
13. Marchant, P.B. 1986. In: Fundamental and Applied Biohydrometallurgy, eds. R.W. Lawrence, R.M.R. Branion and H.G. Ebner, Elsevier, Amsterdam,
14. Marshal, I. 1995. Latin America and the Copper Industry: Growth, Competition and Strategic Positioning. In Proceedings of the 4th Annual MEMS Meeting, Boulder, CO.
15. BC Hydro. 1994. Resource Acquisition Policy, BC Hydro, Resource Planning, Burnaby, B.C.
16. Knopp, R. 1995. Gibraltar Mines Ltd, B.C., personal communication.
17. Drake, J. 1995. Compañia Minera Quebrada Blanca S.A., Santiago, Chile, personal communication.
18. Wright Engineers Ltd. 1985. Catalyzed bioleaching of sulphide copper concentrates - process design and capital and operating cost estimate, Project Report, Vancouver, B.C.
19. Lawrence, R.W., Vizsolyi, A and Vos, R.J 1985. The silver catalyzed bioleach process for copper concentrate, In: Microbiological Effects on Metallurgical Processes, eds. J.A. Clum and L.A. Haas, Metallurgical Society of AIME, Warrendale, PA, 65-82.
20. Brierley, C.L. 1982. Microbiological mining. Scientific American, 247 (2), 44-53.
21. Hiskey, J.B. 1993. An overview of copper heap leaching. Presentation at the University of Arizona.

22. Pfalzgraff, C.L. and Coyne, K.R. 1986 The economics of copper dump leaching and its application to British Columbia's ores. 10th Annual Meeting of District 6 of the Canadian Institute of Mining and Metallurgy, Victoria, B.C., October 4.

23. Hargreaves, D., Eden-Green, M., and Devaney, J. 1994 World Index of Resources and Population. Dartmouth Publishers, Aldershot, England, 417 pp.

24. Baldry, J., 1994. The future of commodity prices. Report by Nesbitt Burns, Toronto, 31 p.

25. Leshy, J. 1987 The mining law. A study in perpetual motion. Washington, D.C., Resources for the Future.

26. Kalin, M. 1994 Data derived from limited polling of selected mining companies.

27. Environment Canada. 1994. A brief examination of the Canadian bioremediation industry. Report issued by Ernst & Young and the Environmental Bio-Industry Council.

28. Mudder, T.I. 1995. Times Ltd, Bozeman, Montana, personal communication.

29. Whitlock, J. 1995. Bioremediation of mine process leach waters. In: Proc. 11th Annual Meeting of BIOMINET, eds. L. Lortie, W.D. Gould and S. Rajan, CANMET publication SP 95-1, Natural Resources Canada, 23-29.

30. Kilborn Inc. 1991. Best available pollution control technology - metal minng sector. Report for Ontario Ministry of the Environment, Metal Mining Sector.

31. Caldwell, C. 1995. Pintail Systems Inc., Denver, CO, personal communication.

32. de Vegt, A. 1995. Paques Environmental Technology, Exton, PA, personal communication.

33. Warkentin, D. 1995. NTBC Research, Richmond, B.C., personal communication.

34. Senes Consultants Ltd. 1994. Acid mine drainage - chemical treatment and sludge management practices. MEND Project 3.32.1, DSS Contract 23440-3-9140/01-SQ, CANMET, Ottawa.

35. SRK Inc., Norecol Environmental Consultants Ltd. and Gormley Process Engineering. 1989. Draft acid rock drainage technical guide. Report to the B.C. Acid Rock Drainage Task Force, Bitech Publishers, Richmond, B.C., 261pp.

36. Gusek, J.J. 1995. Passive treatment of acid rock drainage: what is the potential bottom line? Mining Engineering 47 (3), 250-253.

37. Kuyucak, N., St-Germain, P. 1993. In-situ bacterial treatment of AMD in open pits. Unpublished Research Report, Noranda Technology Centre, Pointe Claire, Québec.

38. Kalin, M. 1995. Boojum Research, Toronto, personal communication.

39. Pearce, D.W. and Turner, R.K. 1990. Economics of Natural Resources and the Environment. Harvester Wheatsheaf, New York, 378p.

40. Kilborn Inc. 1995. Review of passive systems for treatment of acid mine drainage. Report submitted to MEND, CANMET, Natural Resources Canada.

41. Wasserlauf, M. and Dutrizac, J.E. 1982. The chemistry, generation and treatment of thiosalts in milling effluents - a non-critical summary of CANMET investigations 1976-1982. CANMET Report 82-4E.

CHAPTER 4

THE POTENTIAL IMPACT OF BIOTECHNOLOGY ON CANADIAN MINERAL RESERVES

4.1 Introduction and Definition of Terms

The wider use of biotechnological processes could have an effect on the known mineral occurrences by increasing reserves if lower grade ores could be treated or if more efficient production processes could be implemented. Before evaluating eventual changes in reserves, an updated compilation of Canadian mineral reserves is required to gain an appreciation of the current status. Only reserves of known and well defined deposits are considered. Dependable resources figures were not available and would have introduced a lower degree of dependability to the aggregate total.

Economics of individual ore deposit are site specific as each deposit is unique. Minimum grade, for example, is only one element of a broader analysis that would need to include other components such as location, infrastructure, land use, etc. Biotechnologies are currently being used for Cu and Au production and could be appropriate for either specific types of deposits or for other metals if economic and technical justifications materialize. The reserve situation is illustrated by graphs that show cumulative tonnage when minimum grade is changed depending on the scenario adopted.

The source references used for the compilation of commodity reserves were written by different authors using different classification schemes. For clarification we define the following terms:

deposit: a site with a volume and grade reported.

occurrence: a site without a reported volume or grade

resources: an in-situ mineral occurrence quantified on the basis of geologic data and a geologic cut-off grade. For this compilation, resources include those deposits with reserve volumes classified as geologic, inferred, estimated, potential, mineral inventory, speculated and preliminary.

reserves: that part of the resource which could be mined and from which valuable or useful minerals could be recovered economically. For this compilation, reserves include those deposits with reserve volumes classified as probable, possible, proven, indicated, measured and outlined. Also included in this are deposits where the classification of the reserve are unknown.

4.2 Analysis of Reserves

4.2.1 Methodology

The valuation of biotechnology potential in mining includes the compilation and summary of potential reserves that might benefit from biotechnology applications. This includes an assessment of potential reserves of copper, nickel, zinc, gold, uranium and cobalt. The metals selected for consideration are those considered with the highest potential for current biotechnological applications within the Canadian context. Additional criteria used to select commodities were considerations of existing technologies and the supply/demand perspective. We have chosen to consider the processes which have the greatest probability of success to concentrate on a short to medium economic perspective (5-10 years).

The compilation presents results under three groupings:

Group 1: operating mines or deposits committed for production
Group 2: deposits not currently committed for production and
Group 3: tailings and waste rock piles.

The subdivision of the in-situ reserves into groups 1 and 2 is based on the premise that the introduction of a commercial and viable biotechnological process could affect differently each of the two categories. The economics of the exploitation of tailings and waste rock (Group 3) is significantly different than the in-situ reserves and are reported separately. In this case, tonnage and associated metals and grades are not widely available in the literature.

Sources of the reserve values for Groups 1 and 2 are primarily from data compilations released by Natural Resources Canada (formerly Energy, Mines and Resources Canada) (1-4). Other Federal and Provincial Statistical and Geologic Agencies were also contacted for additional information. Sources of reserve values within tailings and waste rock are from a very recent publication by CANMET (5).

4.2.2 Producing mines / deposits committed for production

Data presented in Table 4.1 are derived from the 1993 Canadian Minerals Yearbook (1). The data are compiled by Province and Territory for the individual commodities. The data presented in Table 4.1 are those reserves committed to production that have been delineated at this point in time. Canada is, and will remain, one of the leading producers and exporters of metals based on proven geologic reserves as well as established industry and projected demand (6). In total, Canada ranks within the top 10 producers for twenty two major mineral commodities.

The economic analysis of metal extraction processes, presented in Chapter 3, identified the economic potential and limits of prospective processes. The analysis indicated that metal can be recuperated economically from dumps and lower grade materials using biooxidation for gold and copper. This has implications for the operating mines and deposits committed for production category of reserves. These reserves enjoy, or could in the future, an infrastructure that could make scavenging of values

from dumps practical, thus increasing efficiency, mine life and total production. This increase of reserves and revenues could be critical for marginal operations.

4.2.3 Deposits not committed to being mined

A total of 3,231 deposits were compiled into a database highlighting: Province, identification number, brief description of mineralogy, commodity, grade, reserves and year of reserve calculation. Commodities were ranked as primary or secondary in the deposit based on deposit description. Commodity searches of the created database included copper, cobalt, nickel, zinc, gold and uranium ranked as primary commodities and are presented as Figures 2 to 7. Commodities ranked as secondary were also extracted and analyzed and are presented as Figures 8 (copper) and 9 (gold). Table 4.2 provides a summary of the compilation presented on a Provincial basis for the individual commodities.

To compile Table 4.2, it was necessary to standardize the raw data by:

1. Converting the grade to a predetermined standard. Units for all the metals, except gold, are recorded as percentage (%). For gold, grades are presented in grams per metric tonne (g/t). If a range of average grade was reported, the lower value is used for this compilation. Where grade was reported as a dollar value per ton of gold, a $35 per ounce value was assumed and converted to g/t for deposits reported prior to 1968. If the average grade was not available, or unable to be converted to the standard format, then that deposit was removed from the commodity table.
2. Selecting between reserves and resources. Based on the reserve classification, only those volumes considered reserves, using the above definition, were included in the commodity table.
3. Converting the volume to a predetermined standard (metric tonnes, t). If a range of volumes was available then the lower value was used in this compilation. If the volume was unavailable, or unable to be converted to tonnes, then the deposit is not included in the commodity table.

For analytical purposes, the results are presented in graphs of average grade versus cumulative tonnage. It is assumed that the distribution of grade in the earth's crust is such as to have an exponential increase in quantity following the inverse of the grade. Figure 1 illustrates the general shape of these graphs.

It is reasonable to assume that changes in the production cost structure, for example by consideration of new technology, would be reflected in a change in the cutoff grade. This would have a maximum effect on the deposits not currently committed for production by improving their viability and increasing their numbers in the lower grade end of the curve. Figure 1 can be used to illustrate different forces at work.

The position X_1 represents the status-quo position with respect to tonnage and cut-off grade for a particular process and commodity. The promise of biotechnology has often been portrayed as one which would result in a movement towards X_2. In the absence of new technologies, however, other forces are at work, particularly those related to the trend towards more stringent environmental

regulation. This tends to shift the relationship towards X_3. In this case, we could expect that a new technology will serve to maintaining the position represented by X_1. Our analysis in Chapter 3 has shown that this situation, or even a further movement towards X_2, would need to be supported by the introduction of biotechnology for environmental control so that the introduction of new bio-extractive technologies results in a net gain. This analysis presupposes constant commodity price.

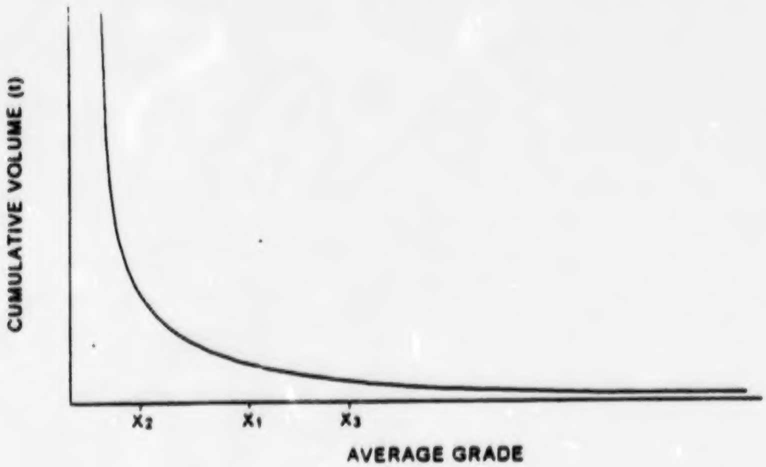

Figure 1. Relationship between average grade of reserve and cumulative tonnage (X represents average cutoff grade)

The analyses in Chapter 3 indicated that replacement or substitution of actual processes by biotechnology- based ones is possible. This has the potential of improving reserves for small deposits, for example refractory gold. However, improvements come in small increments and reserve figures would not see a multi-fold increase.

Figures 2 to 7 (following the text) give an order of magnitude of change, as well as displaying by its divergence from the model shape (Figure 1), the characteristics of the individual metal production (e.g. by product, lithologic occurrence, etc.). The choice of graphs over tables was warranted by the need to portray the effects of change of a wide range of average grade on the cumulative reserves.

Figure 2: *Primary Commodity Gold Reserves*
This graph displays a characteristic standard shape with the inflection point located at 10 g/t. There is a significant increase in reserves at 4 g/t caused principally by large tonnage deposits from B.C.

Figure 3: *Primary Commodity Gold associated with Sulfide Minerals*
Gold deposits reported associated with sulfide minerals are those more susceptible to be of a refractory nature. These reserves are included in the data of Figure 2. Gold associated with sulfide minerals is dominated by ore bodies within Northwest Territories and Ontario.

Figure 4: *Primary Commodity Copper*
The curve for copper does not follow completely the shape of the standard curve. Two distinct inflection points can be observed. A first one at the 1.75% level is caused by massive sulfide deposits and a second at the 0.4% level caused by porphyry ores. Both categories on uncommitted deposits occur mainly within BC.

Figure 5: *Primary Commodity Zinc*
Zinc is a commodity that is frequently mined in conjunction with other commodities. This implies that when present as the primary substance, its economic appeal is often enhanced by the presence of other metals. Also a minimum delineation is done on low grade ores. These two factors give the zinc curve a different shape than the standard one with a step at 6% Zn. The dominant area tonnage is within the Yukon and the Northwest Territories.

Figure 6: *Primary Commodity Nickel*
The curve displayed by nickel has "steps" caused by individual mineral camps. The curve shows, in decreasing grade order, the sequential effect of the Manitoba, Quebec and B.C. reserves.

Figure 7: *Primary Commodity Uranium*
For high grade reserves, the curve of Saskatchewan and Canada are superimposed. The curve displays a standard shape although high grade ore reserves are available. This distortion could be the result of the moratorium on uranium mine development in Saskatchewan.

Figure 8: *Secondary Commodity Gold*
When gold is a secondary metal, it is expected that the grade will be low. The reserves are primarily within B.C. with a grade of 1 g/t.

Figure 9: *Secondary Commodity Copper*
It is apparent from this Figure that ore deposits that rank copper as a secondary metal have a surprising high grade of Cu.

4.2.4. Refractory gold deposits

Since the treatment of refractory gold deposits using biotechnology is a particularly significant commercial application and projected to find greater application, a compilation of refractory gold deposits in Canada is given in Table 4.3. Many other deposits, in which gold is associated with sulfides, might also be refractory. However, these are as yet untested and their potential refractoriness is therefore not considered. Figure 3 includes deposits listed in Table 4.3.

The entrance of STR biooxidation technology at industrial scale has opened up new opportunities in Canada both for greenfield projects and for additional recovery from mill products. Deposits that have the attribute specifically required by this technology could be favoured. Added reserves would come probably from small deposits. The imminent commercialization of bio-heap leaching for lower-grade refractory ores might find application in Canada in the future.

4.2.5 Tailings and waste rock piles

Data presented in Table 4.4 are from a 1994 CANMET compilation of waste material accumulated in Canada (5). The compilation is on a Provincial basis and includes tonnes and hectares of tailings and waste rock. This represents a summary of the waste material volumes containing metals, except iron. Where the volume is not available, the available hectares have been used to estimate the volume based on 150,000 tonnes of tailings per hectare and 400,000 tonnes of waste rock per hectare. There is insufficient information with respect to commodity grades within the tailings and waste rock to comment on the potential for added metal recovery from these mines.

The data in Table 4.4 have been divided into acid potential and base potential mine waste and tailings for the purpose of identifying the extent of the environmental liability related to ARD. There is a high probability that biotechnology will be applied exclusively to the acid potential tailings and waste rock. Current leaching biotechnologies operate under low pH and would likely be feasible only for the rock having an acid potential. It should be noted that these same acid potential rocks within waste piles and tailings are also an economic liability to society. New processes that would contribute to acid effluent control would benefit from economic incentives for environmental reasons.

Table 4.5 separates the Canadian total of mine waste material by type of original mineralization. Tailings and waste rock from non-metallic mines are excluded. No assay results were provided with the data.

Biotechnology applications on waste and tailings produced at operating mines are actually being applied and have the potential of being more widely used. Their use in the re-processing of waste and tailings at non-active sites is also possible. The added benefit of reducing sulfur and metal contents of waste materials and the potential for more environmentally-sound storage after re-treatment should be noted. Companies that wish to embark upon such ventures would need to receive credit for the significant environmental benefits that would accrue.

4.4 References

1. Energy, Mines and Resources Canada, 1993. Canadian Mineral Yearbook, 1992, Review and Outlook, Mineral Policy Sector.
2. Energy, Mines and Resources Canada, 1989. Canadian Mineral Deposits Not Being Mined in 1989, National Mineral Inventory, Mineral Policy Sector, Mineral Bulletin MR 223.
3. Natural Resources Canada, 1994. Canadian Mines: Perspective from 1992, Production, Reserves, Development, Exploration, Economic and Financial Analysis Branch, MR 236.
4. Natural Resources Canada, preprint. Canadian Reserves, Mine Investment, New Projects and Promising Deposits, in Canadian Minerals Yearbook, 1993.
5. CANMET, 1994. report of the Results of a Workshop on Mine Reclamation, Toronto, Ontario, March 10 - 11, 1994. Released at Mines Minister Conference, September 1994.
6. Hargreaves, D., Eden-Green, M. and Devaney, J., 1994. World Index or Resources and Population, Dartmouth Publishing.

Table 4.1. Canadian Reserves by Province and Territory
Contained in Operating Mines and Deposits Committed for production

Metal	Units	Nfld	NS	NB	Que	Ont	Man	Sask	BC	YT	NWT	Canada
Copper	000 t	-	-	234	1,503	4,960	421	-	3,699	-	-	10,818
Nickel	000 t	-	-	-	-	4,160	1,445	-	-	-	-	5,606
Zinc	000 t	-	-	5,738	1,710	1,819	938	-	1,835	1,502	1,524	15,067
Uranium	000 t	-	-	-	-	-	-	-	-	-	-	
Gold	t	27	-	42	309	746	29	2	88	18	97	1,367
Cobalt	000 t					31	36					68

Table 4.2. Canadian Reserves by Province and Territory
Contained in Deposits Not Operating or Committed for Production

Metal	Units	Nfld	NS	NB	Que	Ont	Man	Sask	BC	YT	NWT	Canada
Copper	000 t	3,750	2,440	16,300	417,000	381,000	47,500	48,500	3,640,000	219,000	82,500	5,040,000
Nickel	000 t	-	-	15,600	402,000	222,000	509,000	23,800	466,000	42,600	8,660	1,690,000
Zinc	000 t	30,300	6,740	106,000	128,000	26,000	26,700	21,600	101,000	30,300	132,000	776,000
Uranium	000 t	6,940	-	-	60,300	59,600	-	23,400	8,740	-	4,410	161,000
Gold	t	1,910	11,300	-	97,800	117,000	18,500	30,500	173,000	9,840	71,100	530,000
Cobalt	000 t				9				178			187

Table 4.3: List of Canadian Gold Mines and Deposits that Contain Arsenic, Antimony or Mercury Minerals
(Source: A. Lemieux, Natural Resources Canada)

Mine or Deposit	Province	Tonnes	Average Grade (g/t)
Bannockburn	Ont	337,841	13.5
Beattie Mine	Que	2,060,706	4.5
Congress	B.C.	607,933	8.2
Wayside	B.C.	284,141	1.71 to 5.1
Banks Island - Kim	B.C.	71,952	7.2
Banks Island - Discovery	B.C.	58,407	15.6
Banks Island - Tel	B.C.	71,405	14.5
Cameron Island (Duport)	Ont	1,815,600	12.0
Campbell Red Lake	Ont	-	-
Consolidated Professor	Ont	-	-
Dickenson	Ont	-	-
Capoose Lake	B.C.	28,323,360	0.3 to 35.0
Carolin	B.C.	726,240	4.5
Eskay Creek	B.C.	-	-
Giant Yellowknife	NWT	1,970,834	9.0
Giant Yellowknife - tailings	NWT	9,078,000	4.1
Con	NWT	3,357,730	10.6
J and L	B.C.	3,060,194	5.8
Ketza River	YT	189,730	11.3
Lupin	NWT	2,967,598	9.6
Mount Nansen - Brown McDade	YT	954,030	9.4
Mount Washington (Domineer)	B.C.	plus 301,480	7.1
Nor Acme	Man	3,819,478	6.5
Nor Acme - stockpile	Man	226,950	11.1
Nor Acme - adjacent site	Man	733,230	9.1
Polaris - Taku	B.C.	221,503	11.3
Skukum Creek	YT	465,701	7.6
Tangier Mine	NS	-	-
Tundra	NWT	15,500,000	6.5
Nickel Plate	B.C.	-	-

Table 4.4 : Canadian Reserves by Province and Territory
Tailings and Waste Rock Volumes from Metal Mines (metric megatonne)

		Nfld	NS	NB	Que	Ont	Man	Sask	BC	Yukon NWT	Canada
Acid Potential	Tailings	30	11	77	254	984	200	66	192	64	1,878
	Waste Rock	1	36	26	70	80	69	20	421	17	739
Basic Potential	Tailings	578	7	2	1,630	693	9	325	1,540	149	4,932
	Waste Rock	604	10	1	2,634	48	33	34	2,150	10	5,524
Total	Tailings	608	19	78	1,884	1,677	209	391	1,732	213	6,810
	Waste Rock	605	46	27	2,704	128	102	54	2,571	27	6,263

Table 4.5: Canadian Reserves by Province and Territory
Tailings and Waste Rock from Metal Mines in k tonnes

	Ontario		British Columbia		Manitoba		Saskatchewan		Nfld and Lab		Nova Scotia		New Brunswick		Territories		Quebec	
	Tailings	WR	Tailings	WR	Tailings	WR	Tailings	WR	Tailings	WR	Tailings	WR	Tailings	WR	Tailings	WR	Tailings	WR
Ag															200			
Ag, Au +	8,253	500																
Ag, Co +	7,800																	
Au	22,817	3,300	22,862	320					2,000	500					18,160	1,000	310,200	6,480
Au, Ag	118,655	50															109,200	38,000
Au, Co	100																	
Au, Ni																	11,700	
Au, Cu +	11,709																1,600	800
Au, Ag, Pb, Zn	10,693	1,000																
Au, Ag +	11,554	20																
Cu	1,015		1,343,500	1,426,250					2,400						13,700	380	164,850	140,000
Cu, Au +	19,955	14,400	62,500	76,635					5,700						300	300	29,700	3,800
Cu, Pb/Zn +	110,395	36,600	7,310	26,343	56,950	65,289	65,800		11,802	2			76,500	7,700			160,600	30,400
Cu, Mo (Au, Ag)	185																	
Cu, Ni+	9,875		1,800	180	154,000	36,500												
Mo +	5		208,800	245,000													15,300	400
Ni	63,200	13,000													327			2,000
Ni, Cu +	559,670	36,000															4,050	
Pb, Ag																	750	
Pb, Zn +	1,122		86,500	8,900					13,200						20,600	420	450	
Sn, Cu											18,700	12,846						
U +	190,802	4					25,700	54,080							2,500	7,600		
W +													1,000	1,000	3,000			
Zn															151,000	26,000	2,400	2,000
Zn, Ag																	5,700	88,010
Zn, Cu +	11,460																30,300	3,200
Zn, Pb															800		1,650	
Unknown	45,830	1,500	886	126,680											500			
TOTAL	1,205,095	106,374	1,734,158	1,910,308	210,950	101,789	91,500	54,080	35,102	502	18,700	12,846	77,500	8,700	210,887	35,700	848,850	315,090

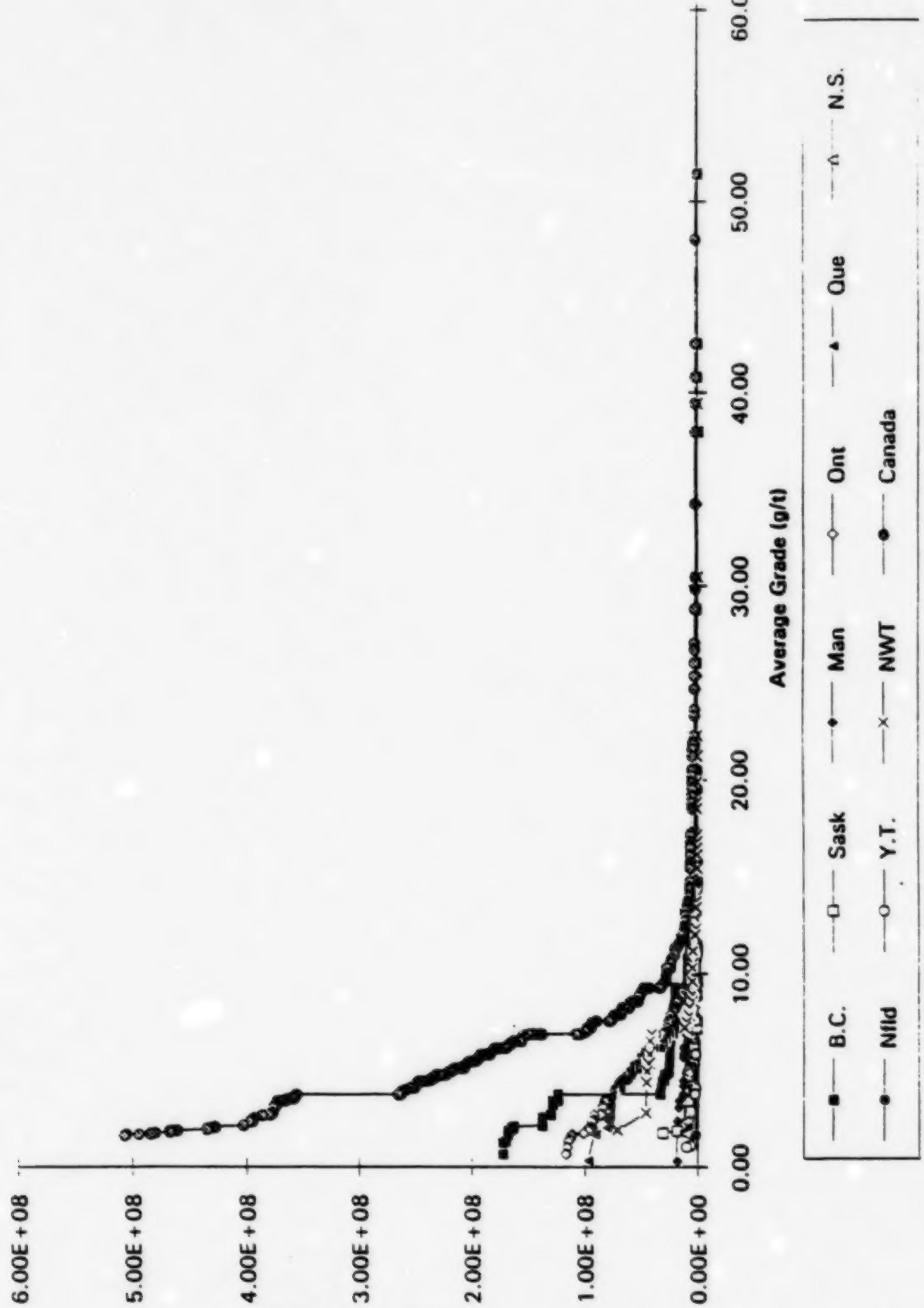

Figure 2. Gold

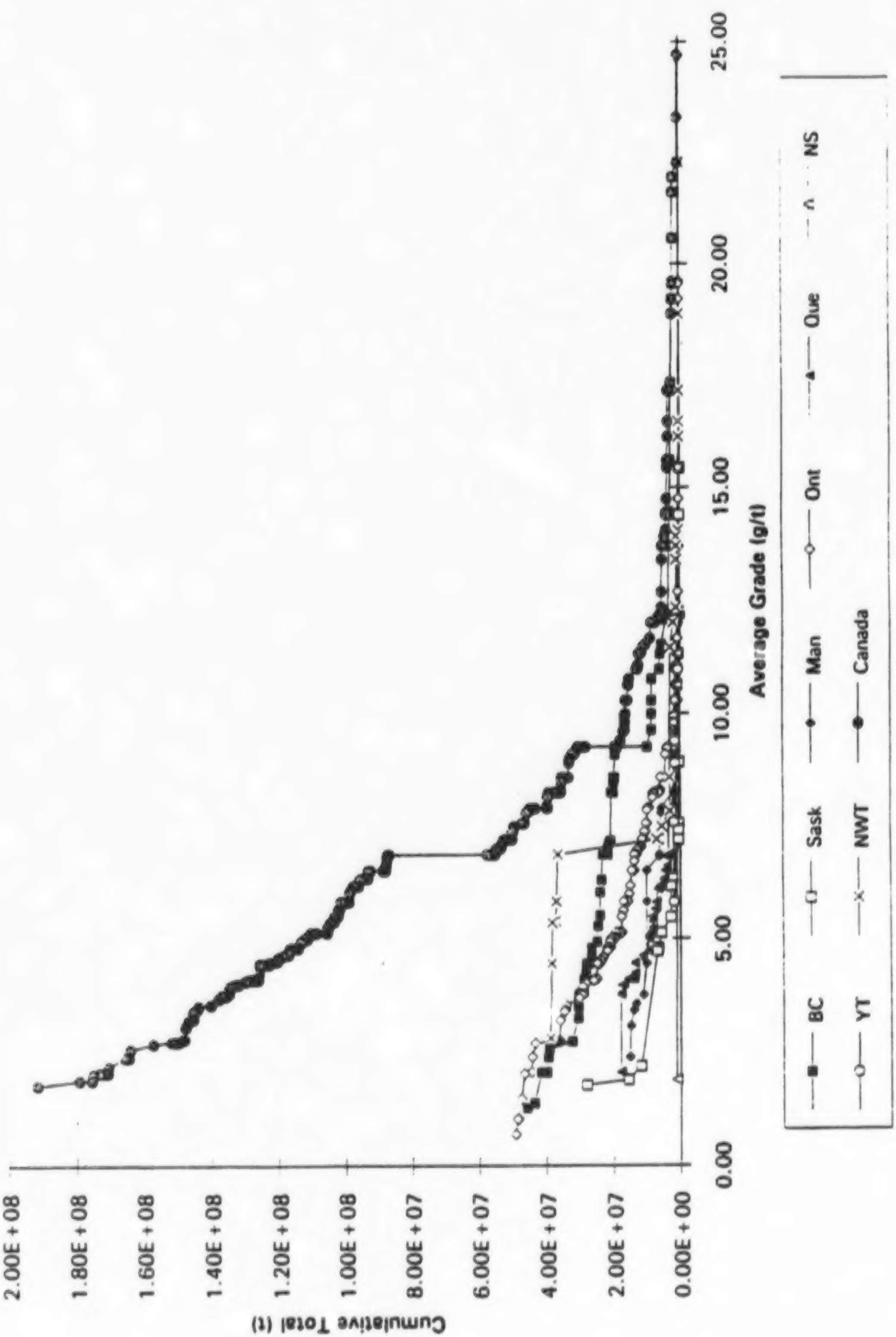

Figure 3. Gold associated with sulfide minerals

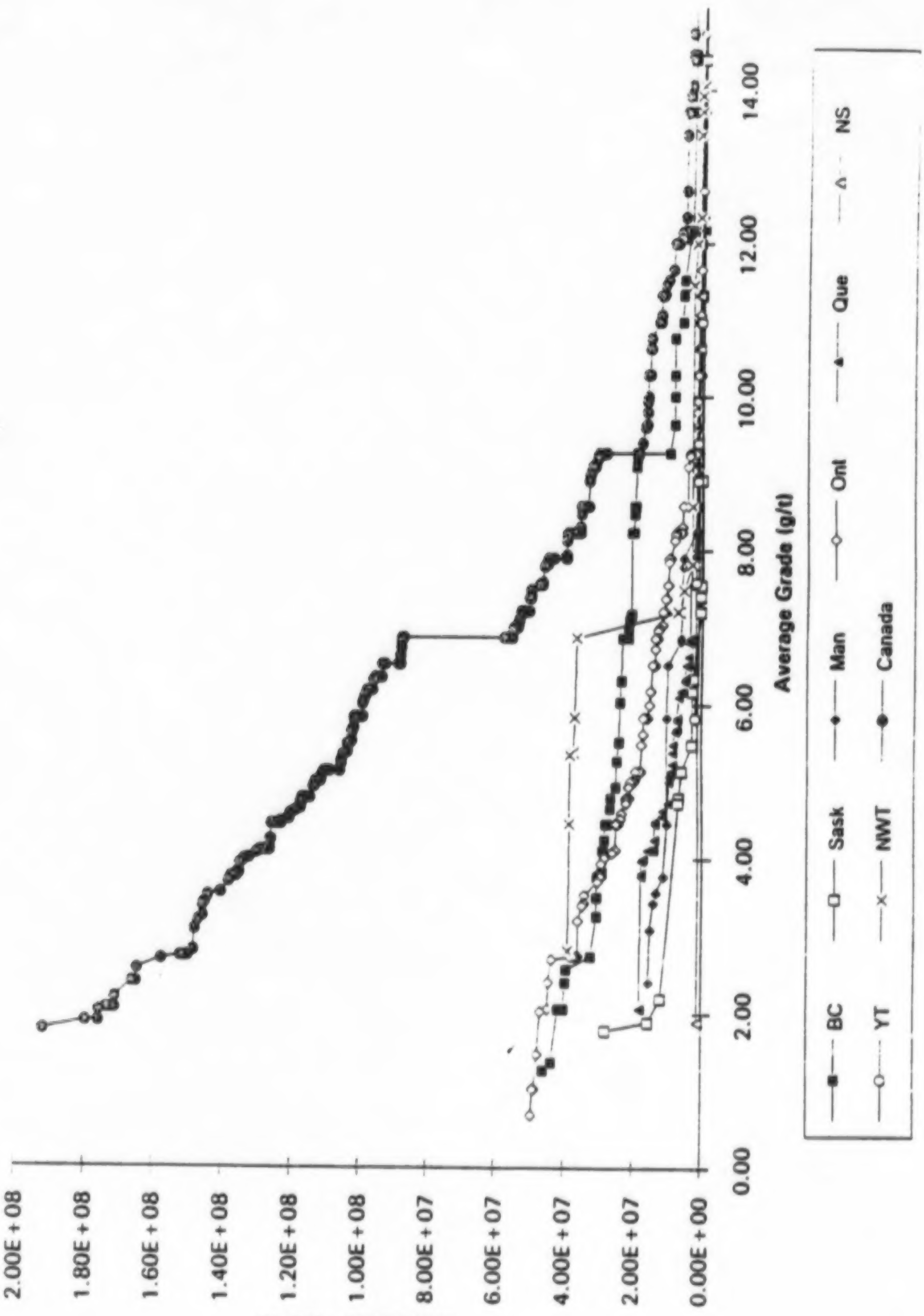

Figure 3a. Gold associated with sulfide minerals

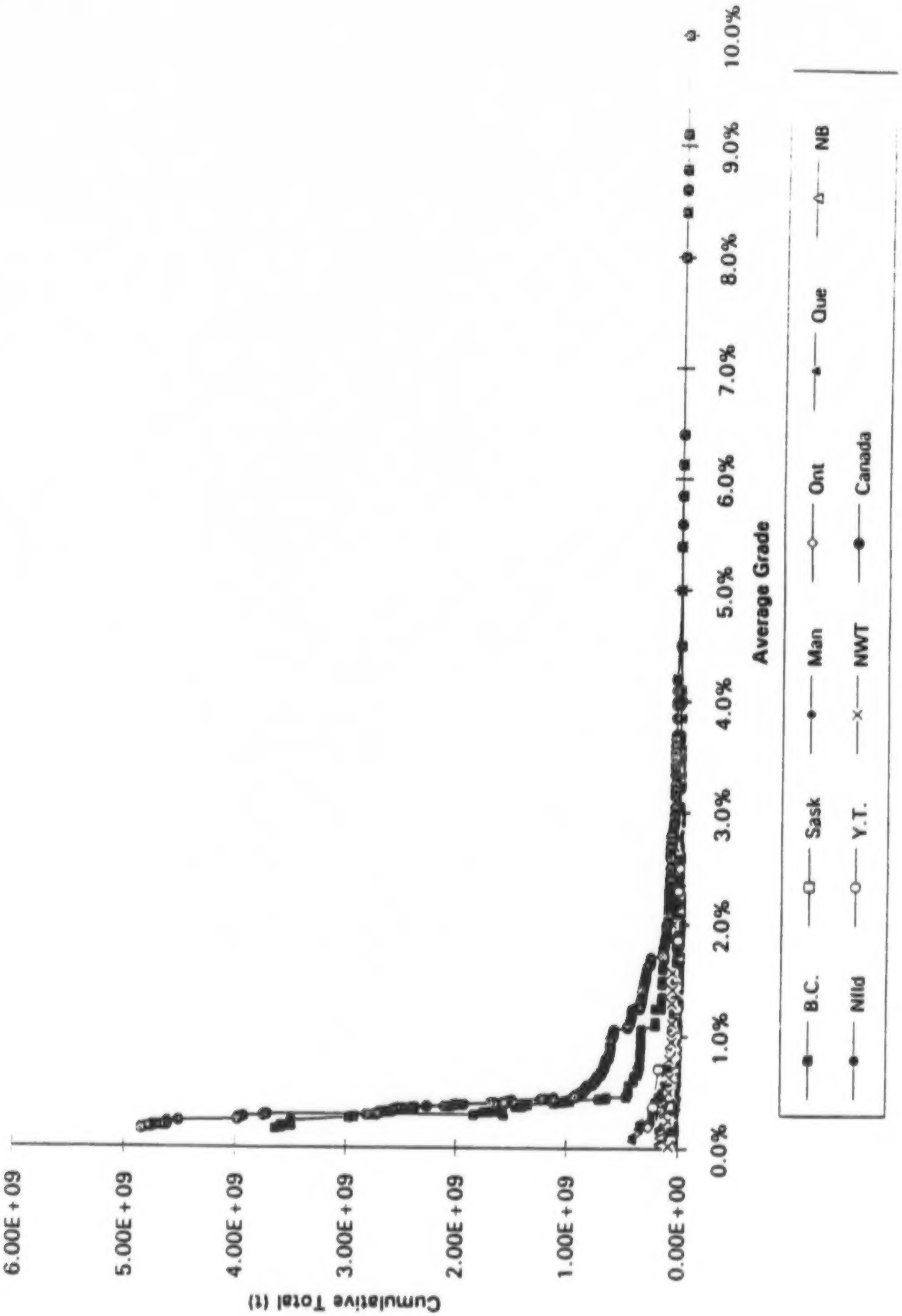

Figure 4. Copper

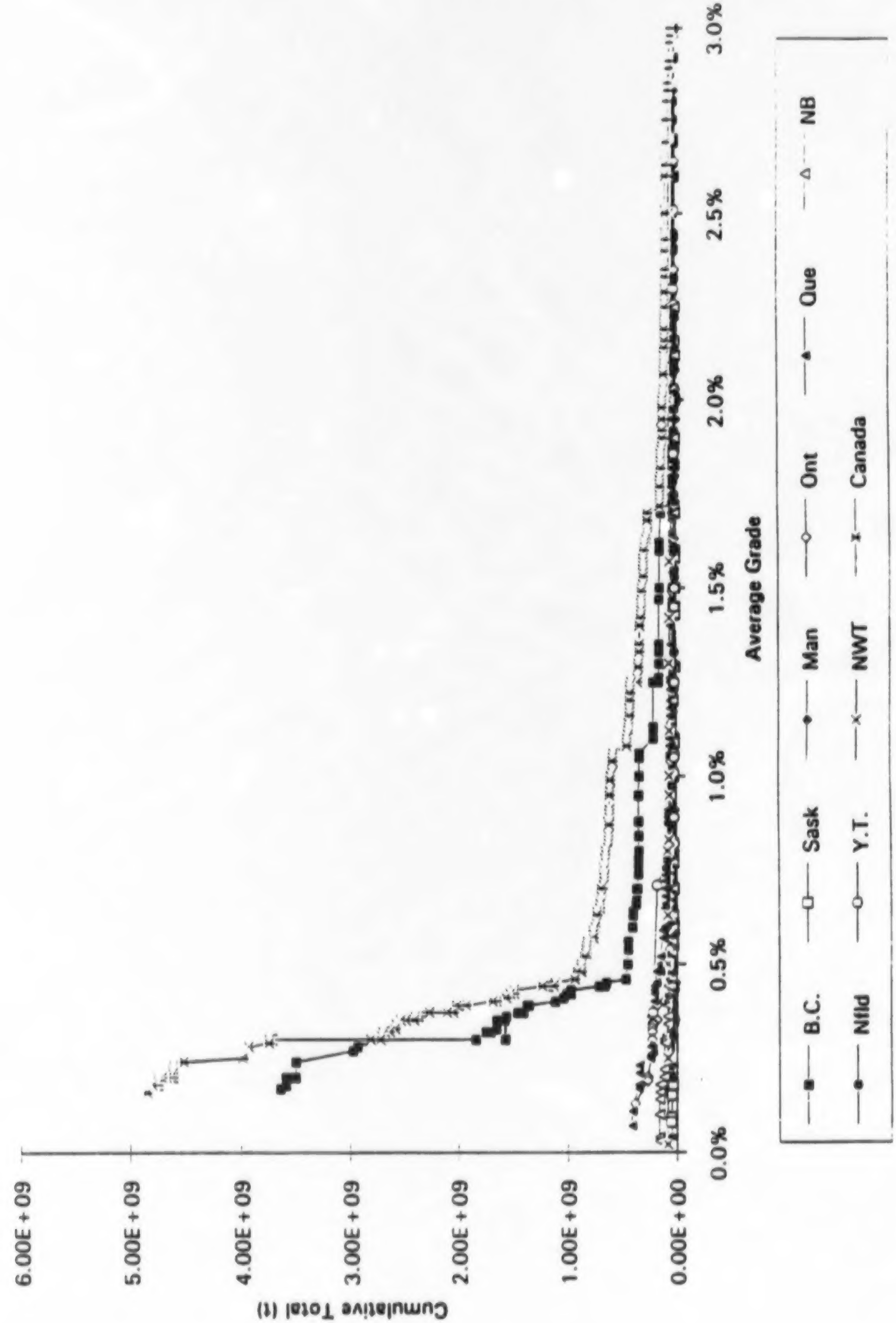

Figure 4a. Copper

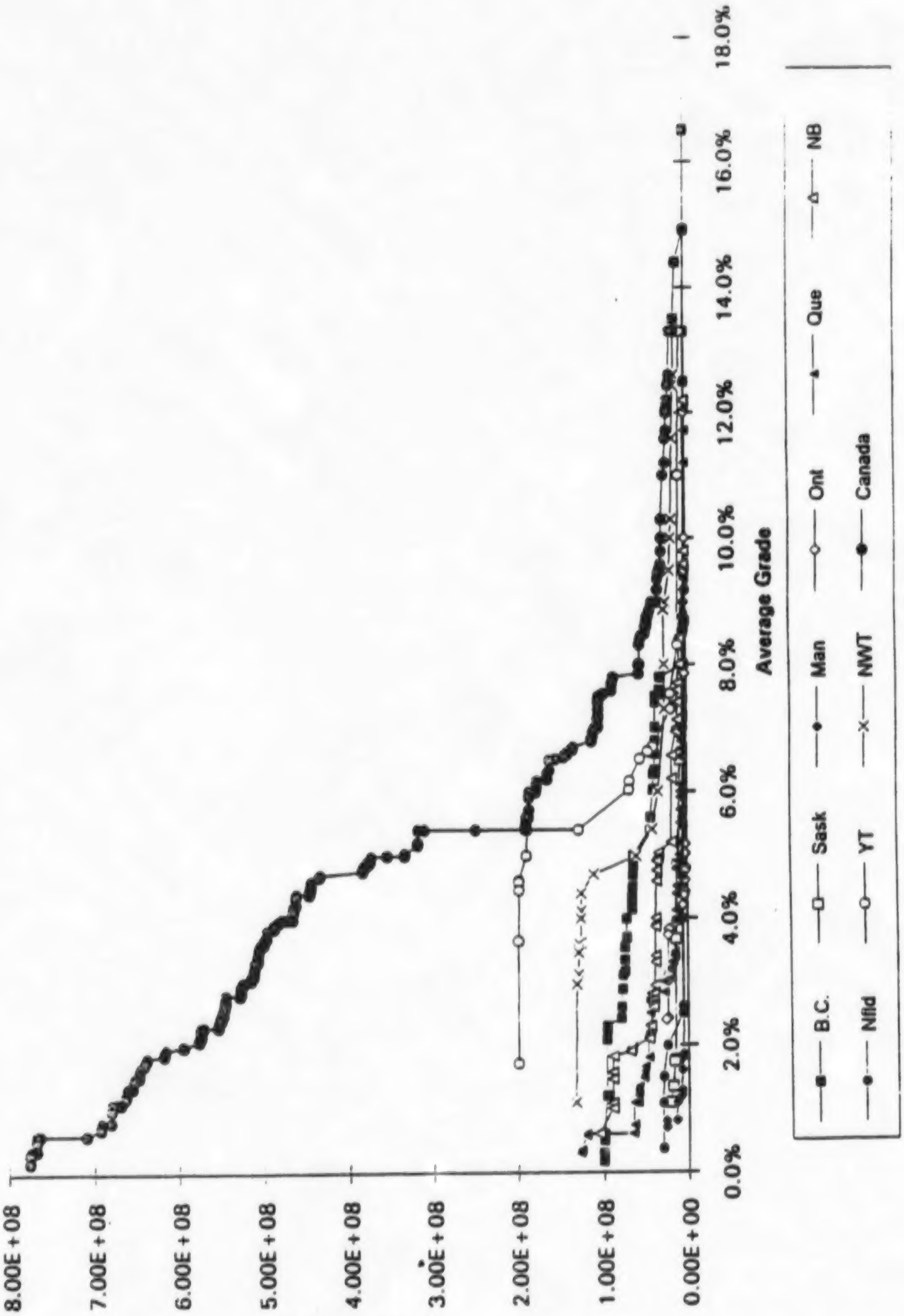

Figure 5. Zinc

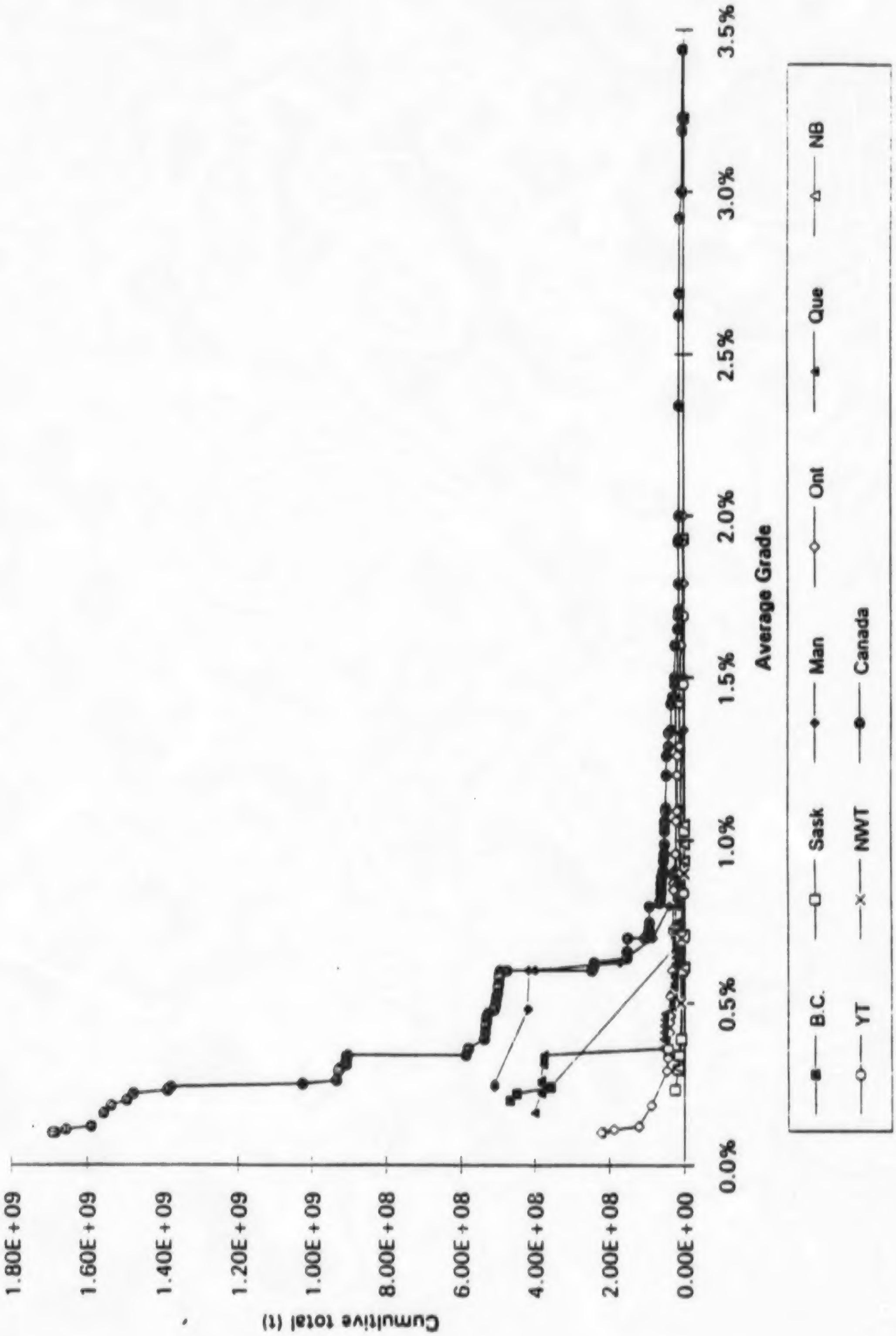

Figure 6. Nickel

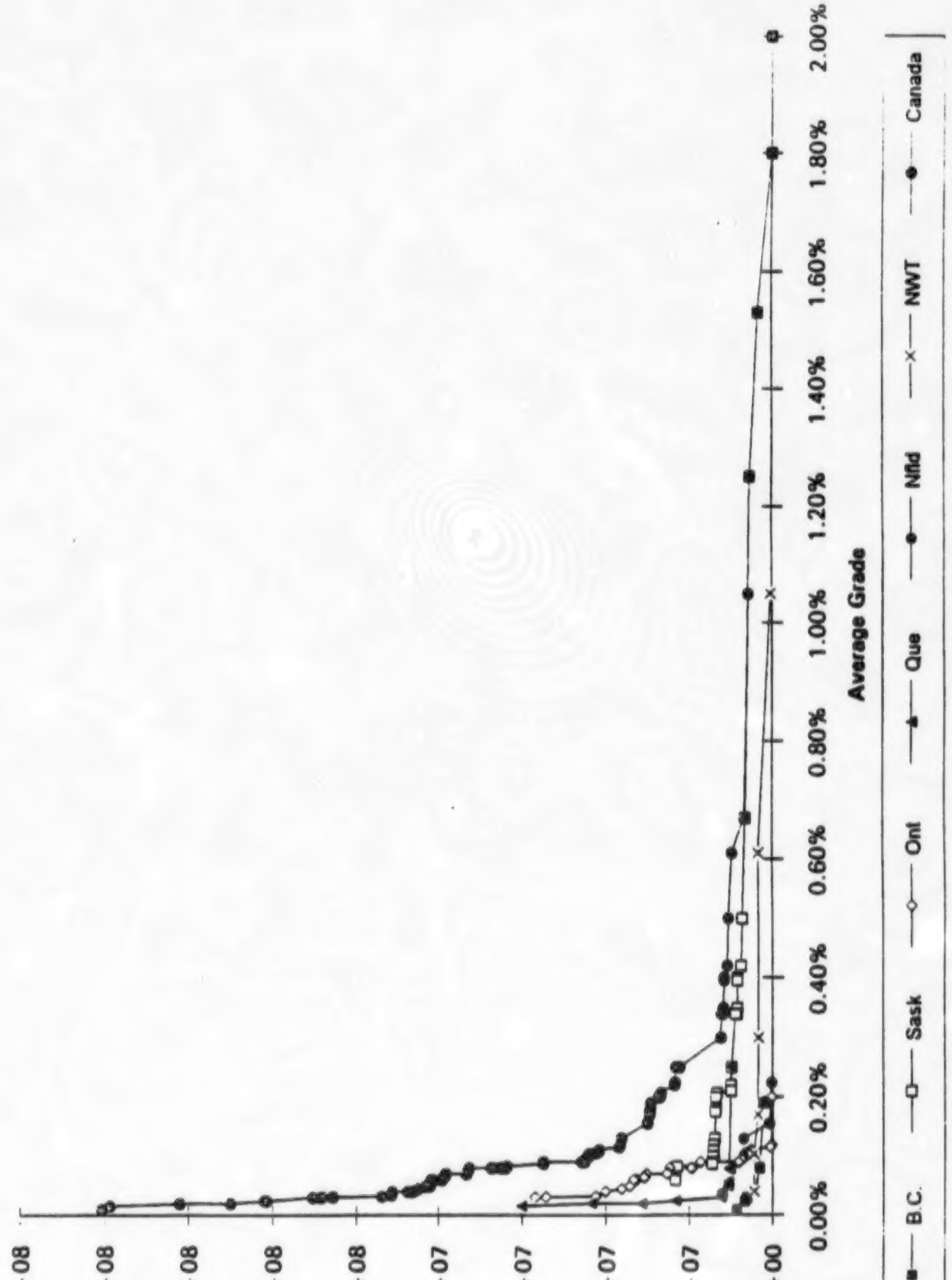

Figure 7. Uranium

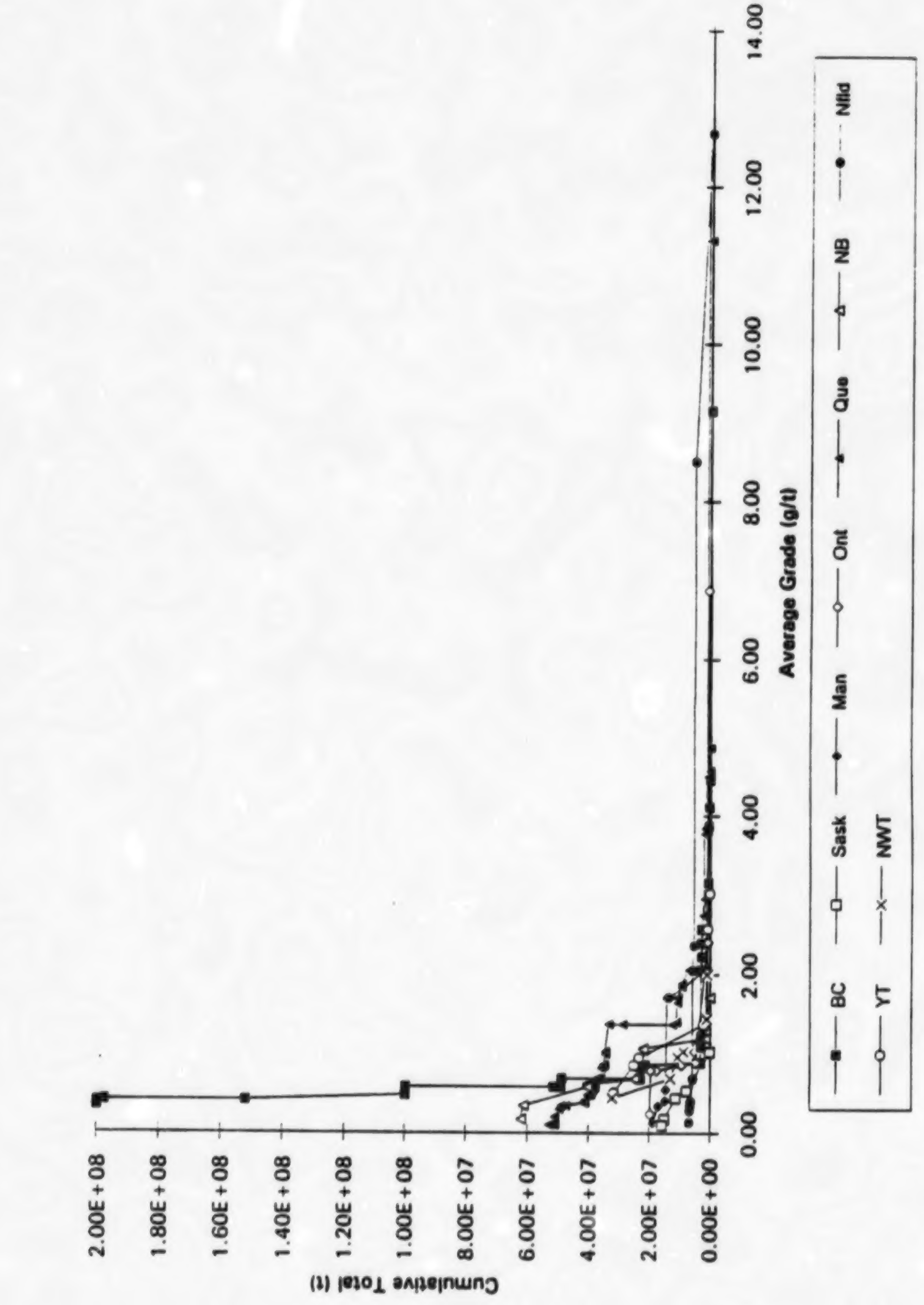

Figure 8. Gold ranked as 2nd value

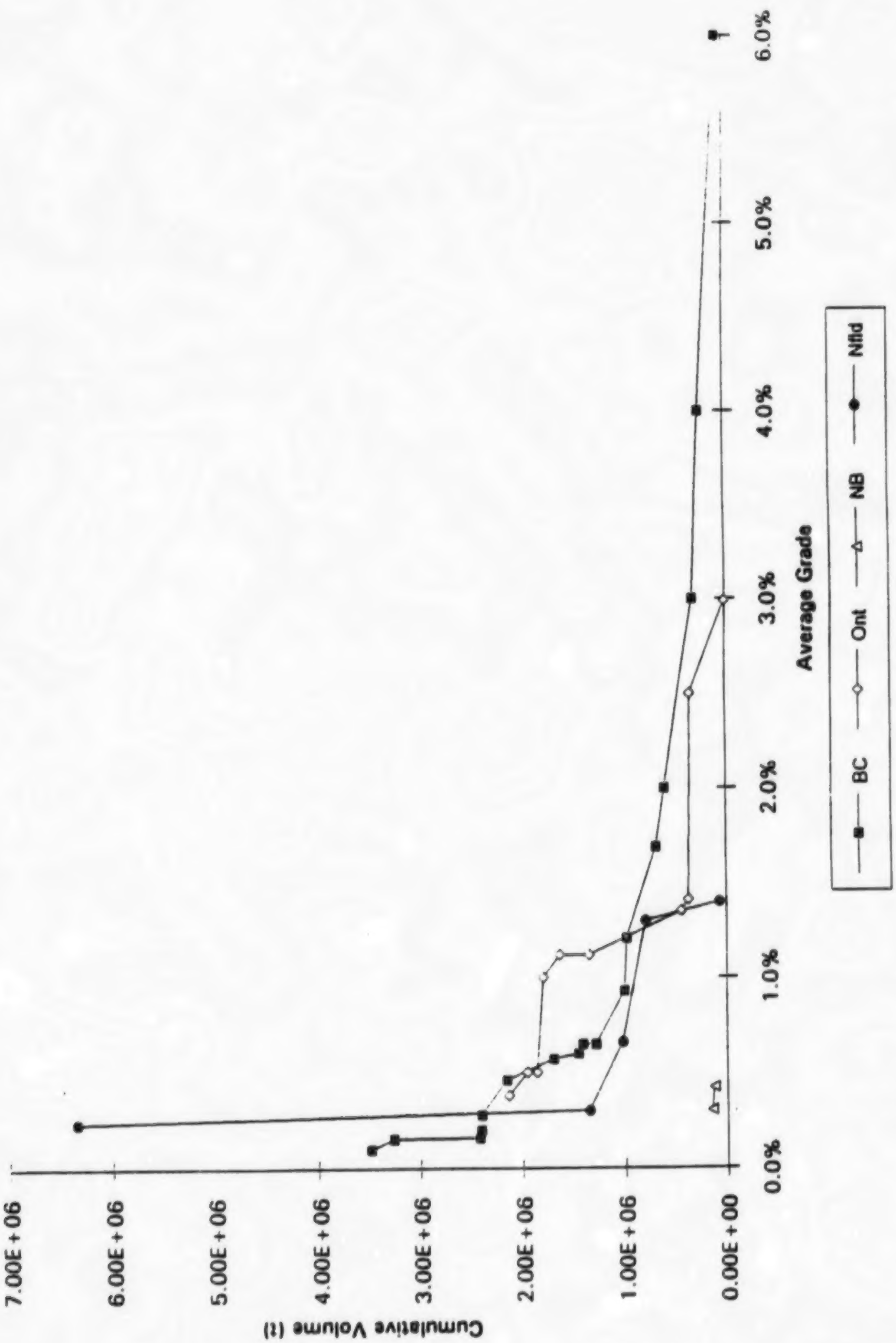

Figure 9. Copper ranked as 2nd value

CHAPTER 5

REGULATORY CONSIDERATIONS ON THE USE OF BIOTECHNOLOGY IN MINING

This chapter provides a review of current and planned regulations relating to biotechnology in Canada. The review begins with a brief look at the history of biotechnology. Key issues relating to the regulation of biotechnology are presented. Following this is an outline of current and planned Canadian biotechnology regulations. Finally, implications of the planned legislation for the Canadian mining industry and actions which will need to be taken are discussed.

5.1 Historical Background

Microorganisms such as *Thiobacillus ferrooxidans* have been aiding the mining industry for hundreds of years by catalyzing mineral leaching processes. These microorganisms are naturally associated with the ores at many mining sites, however their presence was not discovered until the middle of the twentieth century. Since then, biological leaching has developed into a viable process for metal recovery. Interest in biotechnology, principally in sectors other than mining, has grown recently due to the development of genetic engineering techniques, which have the potential to increase both the efficiency of biotechnology processes and the number of substrates that can be biologically treated. The following is a selection of major developments in biotechnology worldwide from 1973 - 1983 (1,2):

1973 The first gene was cloned.

1974 A gene cloned from a different species was first expressed in bacteria.

1975 Guidelines for recombinant DNA (rDNA) research were developed in the United States. [As more information becomes known about rDNA technology, the perceived risk decreases and the US rDNA guidelines have been significantly relaxed since 1975.]

UNESCO (United Nations Education, Scientific and Cultural Organization) established the International Network of Microbiological Resources Centres (MIRCEN). The purpose was to assist in application of biotechnology and distribution of microbial strains.

1976 Genetic Manipulation Advisory Group (UK) was started in the United Kingdom.

US scientists involved in genetic engineering developed self-regulatory guidelines.

1980 The US Supreme Court ruled that microorganisms could be patented under existing laws.

1982 The first rDNA animal vaccine (colibacillosis) was approved for use in Europe.

The first rDNA pharmaceutical product (human insulin) was approved for use in the US and the UK.

1983 UNIDO (UN Industrial Development Organization) established the International Centre for Genetic Engineering and Biotechnology (ICGEB) to help developing countries use biotechnology for food, energy and health.

The following is a history of the developments in Canadian regulation of biotechnology. These developments are discussed later in this review.

June 30, 1988 The Canadian Environmental Protection Act (CEPA) came into effect (3).

1990 *Canada's Greenplan for a Healthy Environment* was issued by Environment Canada (4).

June 13, 1992 Environment Canada published an advisory note in the Canada Gazette, Part 1 to inform Canadian manufacturers and importers of biotechnology products that they were preparing a biotechnology component of the Domestic Substances List (DSL) and that they could obtain guidelines for getting biotechnology products on the DSL (5). (see Appendix I)

Jan 11, 1993 The principles of the Canadian federal regulatory framework for biotechnology products were publicized in a Government of Canada News Release (6).

April 24, 1993 Environment Canada published a second advisory note in the Canada Gazette, Part 1 regarding the biotechnology component of the DSL and addition of biotechnology products to the DSL (5).

Nov 20, 1993 A provisional version of the *Biotechnology Component of the DSL* was published in the Canada Gazette, Part I. Canadian manufacturers and importers of biotechnology products were asked to review and comment on the provisional list and nominate additional substances to the list. Environment Canada began a 90 day period for accepting nominations of biotechnology products for addition to the DSL (5) A second call for nominations will be announced in 1995 (see section 5.4)

Summer 1995 Estimated date of publication of the *Biotechnology Component of the DSL* and the *New Substances Notification Regulations for Biotechnology Products* (7). These publications will contain the regulations, and guidelines affecting the mining sector.

5.2 Key Issues

The guiding principal in the development of regulations, codes of practice and guidelines for biotechnology is that there should be a 'single window' approach, with no new institutions or new legislation created. Working within the framework provided by CEPA, the intention is to provide sector-specific regulations. Assessments of biotechnology products within a given sector will be carried out either under CEPA assessment guidelines or under a CEPA-equivalent evaluation provided by the responsible sectoral department.

A key issue in attempting to regulate biotechnology is the adaptive nature of microorganisms. This issue was raised by the Canadian Mining Working Group in their report to the Director General (8). The characteristics of microorganisms can change in nature and function during their use in biotechnology processes as they adapt to changes in their environment. Therefore, it may be difficult to define a microorganism for placement on the DSL. A similar problem of definition arises when consortia of microorganisms are involved in a process.

Risk assessment is another key issue in the development of biotechnology regulations. A report by the US Congress states that the restrictiveness of a regulation should be balanced against some amount of risk avoided (1). For example, there is a perceived risk associated with the release of large quantities of organisms, either naturally occurring or genetically engineered, into the environment. Many biotechnologies with potential for use in the mining industry, such as biological leaching, bioremediation or biological pollution control, involve the release of microorganisms into the environment. There might be a potential risk associated with these technologies because it may be difficult to control the behaviour and fate of the microorganisms. However, systems are largely self-regulating since many of the organisms used in these technologies can only survive in the very specific environmental conditions provided by the particular application. This is in contrast to in-plant or laboratory systems where the microbial environment is carefully controlled to ensure microbe behaviour and survival.

It may also be difficult to predict how laboratory strains will behave in the natural environment where there are more stresses such as changing conditions (freezing, drought, etc), the presence of competitive organisms, and unique site mineralogy and geochemistry. It has been argued that zero risk is not possible and that regulation must balance the risks and benefits of introducing genetically engineered organisms into the environment (9). A discussion of the issue of risk assessment with respect to the release of genetically engineered organisms into the environment is given in a book entitled *Monitoring Genetically Manipulated Microorganisms in the Environment* (10).

Finally, public perception of the risks associated with biotechnology is very important to regulating this field. Public perception can influence government policy and consequently commercialization of biotechnology (1,11). It is important that the public be involved in the decision making process so that it understands the risks and benefits involved (9). The role of the media in providing information to the public is also important.

5.3 Current Canadian Biotechnology Regulation

In summary, the federal plan for regulating biotechnology in Canada has been established but the regulations are still under development. In particular, methods of regulating microorganisms are currently being discussed by Environment Canada, the provinces and industry. The planned regulations are covered in the next section.

The federal objectives for regulating biotechnology were outlined in *Canada's Greenplan for a Healthy Environment*. The Greenplan called for the following actions regarding biotechnology (6):

- **A federal regulatory framework for biotechnology products to be in place by 1993.** The principles of this framework were published in January, 1993. Of key importance is the fact that biotechnology regulation will be integrated into existing sectoral legislation, ie. industry specific legislation. Biotechnology will not be regulated as a separate industry.

- **Regulations, standards and guidelines for environmental protection and protecting human health following accidental or deliberate release of biotechnology products.** These standards are currently under development by Environment Canada and Health Canada and are expected to be promulgated by summer 1995. The proposed national standard that will likely affect the mining industry is entitled *Microorganisms and Biochemical Products*.
- **Specific regulations requiring notification of new biotechnology products prior to release or introduction to the environment.** These regulations fall under CEPA.

CEPA is not use or location specific; it does not infringe on provincial jurisdiction. Biotechnology processes are subject to health, environmental and other provincial legislation, once their biotechnology products have been approved for import or manufacture in Canada under CEPA. The following sections of CEPA relate to the notification of new biotechnology products (3):

- Section 25 (1,4). Environment Canada will compile and publish in the Canada Gazette a *Domestic Substances List (DSL)*, which is a list of substances that were *'in use'* in Canada between January 1, 1984 and December 31, 1986. *'In use'* is defined for the purposes of CEPA as "manufactured in or imported into Canada by any person in a quantity of not less than 100 kg in any one calendar year; or in Canadian commerce or used for commercial manufacturing purposes in Canada". The DSL will be updated as required and republished in the Canada Gazette.
- Section 25 (2,4). Environment Canada will compile and publish in the Canada Gazette a *Non-Domestic Substances List (NDSL)* of substances that are not on the DSL but are presumed to be in commerce in another country.
- Section 26 (1,2). Any new substance must be assessed for toxicity by Environment Canada before it is manufactured, imported or released into the environment. The assessment will be based on the potential risk to the environment and to human health. Environment Canada must be given sufficient information for assessing the substance.
- Section 26 (3a). Substances that are regulated under other Acts of Parliament, which provide for pre-notification and assessment, are exempt from the CEPA notification requirements for the uses regulated under those Acts. The purpose of this section is to allow regulation of biotechnology within existing sectoral legislation.
- Section 28. This section requires that Environment Canada assess the information within a certain time frame to determine the toxicity of the substance.
- Section 29. This section gives Environment Canada three options regarding the substance: (i) unconditional addition to the DSL, (ii) conditional notification to manufacture or import, (iii) prohibition of manufacture and/or import.
- Section 32. Under this section, Environment Canada must regulate the import or manufacture of any substances that are not on the DSL. The regulations are called *New Substances Notification Regulations*. They will include information schedules that list the information required by Environment Canada for carrying out an assessment. There will be different information schedules depending on the nature of the substance and the risk associated with it.

Environment Canada has decided to publish two Domestic Substances Lists; one for chemicals and polymers and the other for biotechnology products. To date, the DSL for biotechnology products has not been published. The DSL for chemicals and polymers was published in the Canada Gazette, Part I on January 26, 1991. It was updated and republished in the Canada Gazette, Part II on May 4, 1994 (12). The DSL for chemicals and polymers is in two parts: part one includes the majority of the substances listed by their Chemical Abstracts Service Registry Numbers, and part two includes substances that have a masked name for purposes of business confidentiality (provisions of the CBI, confidential business information). Part two substances are named according to the *Masked Name Regulations* under CEPA Section 32, which will also apply to biotechnology products. These regulations were published in the Canada Gazette, Part II on April 6, 1994 and are given in Appendix I (13).

The NDSL *(Non-Domestic Substances List)* was developed from the US 1985 Toxic Substances Control Act (TSCA) list of substances. It includes substances that are on the 1985 TSCA list but not on the DSL. There were some biochemical biotechnology products on the 1985 TSCA list, however these were omitted from the Canadian NDSL. The NDSL was published in the Canada Gazette, Part I on January 26, 1991. It was subsequently updated and the changes were published in the Canada Gazette (14). There are currently no biotechnology products on the NDSL although a biotechnology component might eventually be developed (14).

To date, no notification regulations for biotechnology products have been published. Information requirements for chemicals and polymers are given in the *New Substances Notification Regulations*, which were published in the Canada Gazette, Part II on April 6, 1994 (15).

5.4 Planned Canadian Biotechnology Regulation

Environment Canada plans to publish a separate DSL for biotechnology products entitled *Biotechnology Component of the Domestic Substances List*. A provisional list for the biotechnology component of the DSL was published in the Canada Gazette, Part I on November 20, 1993 (5); a copy of this publication is given in Appendix I. The provisional list consisted of one microorganism, *Saccharomyces cerevisiae*, and nine substances produced from microorganisms or other organisms. Environment Canada began accepting nominations for addition to this list on November 20. Environment Canada would then have 90 days to respond to the nomination, with no response within the specified time allowing use by the nominee. The information that was to be submitted with each nomination was given in the provisional list (see Appendix I). The regulations have been delayed due to the difficulty of developing nationwide regulations for live organisms. A second call for nominations to the list will, therefore, be made prior to the publication of the list sometime in 1995 (6).

The federal government is currently under negotiation with the provincial governments and industry concerning regulation of the biotechnology products that are accepted on the DSL. The federal objective is to integrate biotechnology regulation with existing legislation for relevant industries. The difficulty is that there are no existing federal or provincial regulations relating to biotechnology

products, such as exist for many chemical products. For example, chemical fertilizers are already regulated in Canada under the Fertilizers Act and pharmaceuticals are regulated under the Food and Drugs Act. Some biochemicals, such as enzyme products which find application in processing reagents, fall under CEPA regulations.

Information requirements for new biotechnology products will be set out in the *New Substances Notification Regulations for Biotechnology Products*. These notification regulations are expected to be ready for publication in 1995 (7). Notification requirements are not expected to be arduous. Examples of possible information requirements for a biotechnology product produced from an organism, such as an enzyme, are name(s), name of source organism and amino acid sequence. Information requirements for live microorganisms will include process descriptions, mechanisms for entry into the environment, quantity and length of exposure to other organisms and potential effects on other organisms. Notification for a genetically engineered microorganism could require additional information such as its stability and its potential for gene transfer to other organisms. The regulations will contain several information schedules with information requirements that vary depending on the level of risk to human health and the environment.

Notification regulations will be the same for naturally occurring and genetically engineered microorganisms. The provisional list for the biotechnology component of the DSL stated that naturally occurring microorganisms will be automatically on the DSL even if they are not listed individually. However, this automatic acceptance of naturally occurring organisms will probably *not* be part of the forthcoming regulations since inclusion would allow use for any purpose rather than the specific application (7). Consequently, there will possibly be very few microorganisms on the biotechnology component of the DSL. The main reason for this is that the DSL was designed for chemicals, not for live organisms. Any substance that is placed on the DSL may be imported or manufactured in Canada with no requirement for future assessment. However, the risks associated with microorganisms are related to the end use and the location of end use. A great deal of information would be required to do a nationwide assessment of the risk of importing or manufacturing a microorganism for any use in any part of Canada.

Instead, Environment Canada is considering the issue of conditional notifications to import or manufacture microorganisms in specific *ecozones* in Canada. An *ecozone* is a contained or confined system with particular physical or environmental conditions such that the microorganism cannot grow outside the system. An *ecozone* is the lowest level that Environment Canada can assess under CEPA, without becoming site specific. Conditional notifications are the second option available to Environment Canada under Section 29 of CEPA regarding new substances. Since the notifications will be conditional, the microorganisms will not be placed on the DSL, which is an unconditional list. Once a conditional notification has been issued, the biotechnology process will still be subject to provincial health and environmental legislation.

Once the notification regulations are in place, a company wanting to operate a biotechnology process must follow the notification procedure to get a biotechnology product on the DSL or to obtain a

conditional notification for import or manufacture of a microorganism. If a conditional notification has already been issued by Environment Canada for a similar ecozone, the company must still follow the entire procedure. The only exception to this would be if the company holding the existing notification has signed the waiver in their application agreeing to share their information. In this way, industry may decide to share information required under the notification requirements to reduce the time for obtaining conditional notifications from Environment Canada.

Companies already using microorganisms or other biotechnology products will still be required to provide notification to Environment Canada once the regulations are in place. However, there will be provision in the regulations for *transitional substances* or new substances that were imported or manufactured in Canada between December 31, 1986 and the date the regulations are published (7). These provisions will require all companies using a transitional substance to notify Environment Canada but the company will be allowed to continue operating the biotechnology process. These provisions will apply unless it is determined by Environment Canada that the substance(s) involved should be prohibited from import or manufacture in Canada. The company will be required under CEPA Sections 17 and 18 to report any adverse effects of the biotechnology process on human health and the environment to Environment Canada.

5.5 Required Action by the Mining Industry

By Summer 1995, the *Biotechnology Component of the Domestic Substances List* and the *New Substances Notification Regulations for Biotechnology Products* will be published. Once this occurs, the following actions will be required for continued use, new import or manufacture of biotechnology products in Canada. There will be essentially three cases:

Case A: The biotechnology product is already on the DSL

1. Proponents will need to determine if the biotechnology product involved in the biotechnology process is on the list entitled Biotechnology Component of the DSL. If it is, then there are no further requirements for import or manufacture of the substance in Canada. (Note: if the biotechnology process involves a microorganism, then that microorganism is not likely to be on the Biotechnology Component of the DSL. However, notable exceptions such as *Thiobacillus ferrooxidans* might be considered for the list (6)).

Case B: The biotechnology product is not on the DSL but is already in use (ie. it is a transitional substance)

1. If the biotechnology product is not on the DSL but it is a transitional substance because it was imported or manufactured in Canada between December 31, 1986 and the regulation publication date, then Environment Canada should be notified by the user as required by the New Substances Notification Regulations for Biotechnology Products. Failure to notify could result in significant penalties.

2. Continue to use, import or manufacture the biotechnology product under the current conditions.

3. Report any adverse effects of the biotechnology process on human health and the environment to Environment Canada.

Case C: The biotechnology product is not on the DSL and it is a new substance

1. The proponent needs to determine which information schedule given in the New Substances Notification Regulations for Biotechnology Products applies to the proposed biotechnology process.
2. Compile the information listed in the appropriate information schedule. Under the provision of CBI (Confidential Business Information), a request for allocation of a masked name of products and microorganisms can be applied for. The specifics of the application will not then be released.
3. Send the completed information schedule to Environment Canada.
4. If the biotechnology product is approved for unconditional import or manufacture in Canada, then proceed with development of the biotechnology process. If the biotechnology product is a microorganism that has been conditionally notified under a single ecozone schedule, then proceed with development of the biotechnology process according to the conditions of the notification.

   Environment Canada will need to respond to an application within 90 days of receipt. Failure to respond in this time period will allow the applicant to proceed with the biotechnology process development.

Application for use, manufacture or importation of biotechnology products can be made by the mining company or the supplier of the product on behalf of the company. Details of application procedures will be made widely available by Environment Canada through the Canada Gazette, regional offices, associations, computer databases and the Internet. Hot lines will be set up to assist with applications.

5.6 Regulations in Other Jurisdictions

Although a review of foreign regulation of biotechnology is beyond the scope of this study, it is important to note how Canadian regulations compare to those of other countries. Canadian global competitiveness depends on not having regulations that are significantly more restrictive than those of its competitors. Currently, Canada's approach to biotechnology regulation is similar to the approaches taken by the United States, the European Community and OECD (Organization for Economic Cooperation and Development) (6). The Canadian treatment of microorganisms as new substances is similar to the US treatment of microorganisms as "chemical substances" under TSCA (Toxic Substances Control Act) (1). TSCA, however, covers only genetically engineered organisms; it does not cover naturally occurring organisms (8). In the US, naturally occurring organisms are regulated by individual states and are also covered under several federal acts for the purposes of federally funded projects. The US recently issued a list of genetically engineered organisms (7). The Canadian regulations will conform to recommendations on safe use of biotechnology made by the UN Convention on Biodiversity (6). Therefore, the Canadian regulations are comparable to the US and the EC. It was

not determined in this study how Canadian regulations compare to those of other competitor countries such as Brazil, Chile, South Africa and Russia.

5.7 References

1. U.S Congress, Office of Technology Assessment, Commercial Biotechnology - An International Analysis, Washington, D.C., OTA-BA-218, January, 1984, (1984).
2. Caldwell, L.K., International Environmental Policy - Emergence and Dimensions, Second Edition, Duke University Press, Durham, USA, (1990).
3. Eco/log Information Services, Canadian Environmental Protection Act (CEPA), Canadian Pollution Legislation; Monthly Supplements, Toronto, Ontario, (July, 1994).
4. Environment Canada, Canada's Greenplan for a Healthy Environment, Minister of Supply and Services Canada, En 21-94/1990E, (1990).
5. Environment Canada, Biotechnology Component of the Domestic Substances List - Provisional List, Canada Gazette, Part I, Vol. 127, No. 47, November 20, 1993, pg. 3498 - 3502, (1993). see Appendix I
6. Mahon, D.C., Commercial Chemicals Evaluation Branch, Environmental Protection Service, Environment Canada. Personal communication , 1994.
7. Mahon, D.C., The Environmental and Regulatory Dimensions of Biotechnology Under the Canadian Environmental Protection Act: An Overview, Proceedings of the Tenth Annual General Meeting of BIOMINET, Gould, W.D., Lortie, L., Rodrigue, D. (editors), October 28, 1993, Mississauga, Ontario, (1993).
8. Kalin, M., Report of the Working Group Mining, report submitted to the Director General, Environmental Protection, Environment Canada, June, 1993, (1993).
9. Davis, B.D., The Genetic Revolution - Scientific Prospects and Public Perceptions, The John Hopkins University Press, USA, (1991).
10. Edwards, C. (editor), Monitoring Genetically Manipulated Microorganisms in the Environment, Wiley Biotechnology Series, John Wiley and Sons Ltd., Great Britain, (1993).
11. U.S. Congress, Office of Technology Assessment, Impacts of Applied Genetics, Micro-Organisms, Plants, and Animals, Washington, D.C., OTA-HR-132, April, 1981, (1981).
12. Environment Canada, Domestic Substances List, Canada Gazette, Part II, Vol. 128, No. 9, May 4, 1994, pg. 1854-1955, (May, 1994).
13. Environment Canada, New Substances Notification Regulations, Canada Gazette, Part II, Vol. 128, No. 7, April 6, 1994, pg. 1443 - 1495, (April, 1994).
14. Stringer, G., Commercial Chemicals Evaluation Branch, Pollution Prevention Directorate, Environment Canada. Personal communication, August 4, 1994.
15. Environment Canada, Masked Name Regulations, Canada Gazette, Part II, Vol. 128, No. 7, April 6, 1994, pg. 1496 - 1501, (April, 1994).

CHAPTER 6

RESEARCH AND DEVELOPMENT EXPENDITURES ON BIOTECHNOLOGY IN MINING

6.1 Introduction

Canada has been a major player in the development of biotechnological applications in mining over the past 30 years or more. Many of the important developments and breakthroughs in mining biotechnology which have found application around the world, were achieved in the laboratories of the federal government, provincial research organizations, private research companies, universities and industry.

Funding of these efforts has come from a large number of sources including federal government departments and agencies including Energy Mines and Resources, (now Natural Resources Canada), National Research Council (PILP and IRAP programs), NSERC, and Industry Science and Technology Canada through the National Biotechnology Strategy/Biotechnology Development Program; through programs delivered by organizations such as the B.C. Science Council; and from private industry.

In the environmental field, considerable research effort has been coordinated through the Mine Environment Neutral Drainage program (MEND) and its predecessors, the Reactive Acid Tailings Program (RATS) and the National Uranium Tailings program (NUTS). Many of the projects in these programs have evaluated biotechnology-related processes and their fundamentals. Much of the project funding through these programs has come from Federal and Provincial government sources (including the Mineral Development Agreements) and from the mining industry.

B.C. Research Council was a particularly prominent laboratory performing mining related biotechnology R and D from the 1950's through to the 1980's, receiving funds from most of the above sources. More recently, a number of small entrepreneurial companies have also been involved in biotechnology development funded from private investors or cash flow generated from other activities and services.

Biotechnology expenditures by the federal government have been in a number of sectors represented by Agriculture, the Canadian Forest Service, Environment, Fisheries and Oceans, Health and Welfare, the Medical Research Council, Industry Science and Technology, National Defense, NSERC, Western Economic Diversification, the National Research Council, and Energy Mines and Resources. Smaller expenditures have been made by other departments and agencies. Expenditures on mining related activities by EMR (NRC) have been a low percentage of the total.

A complete compilation of all sources, disbursements and amounts of funding, either in total or for specific projects, is not possible in the context of this report. Many of the data are either not compiled

in a form allowing easy analysis or summation, or are not available for disclosure. As information is made available, the compilation will be revised.

6.2 Federal Expenditures on Biotechnology in Mining

Natural Resources Canada, NRCan, formerly Energy Mines and Resources, and specifically the Canadian Centre for Mineral and Energy Technology (CANMET), the research branch of NRCan, has been the principal federal department involved in biotechnology in mining since 1959. Research is carried out within CANMET in a number of biotechnology areas. Research has also been contracted out to research and development groups across Canada, including industry, for at least ten years. CANMET is also the focus of BIOMINET, a network formed in 1983, that disseminates new developments throughout the industry.

The following compilation (Table 6.1) is from data supplied by Industry Canada and provides an indication of expenditures related to biotechnology in mining by EMR since 1981. In addition to expenditures in specifically mining areas, including bioleaching and environmental control applications, expenditures at EMR have been in several other areas including biocorrosion, biofouling, hydrocarbon recovery, development of microbial products for oil drilling and recovery, hydrothermolysis of wood, lignocellulose conversion, biomass fermentation, biological control of methane, conversion of methane into methanol, and renewable energy programs. For some years, data received do not allow an assessment of funds spent on specifically mining related projects.

Table 6.1. EMR biotechnology spending estimates, 1981-92

Fiscal Year	Expenditures ($000)			
	In-House	Contracts	Total	Mining Sector
1981-82	15.0	100.0	115.0	
1982-83	30.0	75.0	105.0	
1983-84	40.0	785.0	825.0	
1984-85	75.0	1,025.0	1,100.0	500.0
1985-86	75.0	1,200.0	1,275.0	525.0
1986-87	300.0	1,075.0	1,375.0	938.0
1987-88	300.0	1,075.0	1,375.0	715.0
1988-89	420.0	1,325.0	1,755.0	830.0
1989-90	615.0	2,100.8	2,715.8	546.7
1990-91	720.0	2,367.0	3,087.0	525.6
1991-92	670.0	2,171.5	2,841.5	357.9

Not included in the above figures are significant expenditures for research carried out by other federal laboratories to provide enabling technologies in fundamental biotechnology techniques. For example, the Biotechnology Research Institute in Montreal has contributed to minerals-related biotechnology by focusing on the molecular biology/genetics aspects of leaching organisms and has interests in bioremediation and environmental risk technologies, and the development of environmentally benign processes

The following data (Table 6.2), supplied by CANMET, estimates the funding supplied by CANMET for external research projects in mining-related biotechnology. Most of the contracts were funded with National Biotechnology Strategy (NBS) funds. Not shown in the following table, are the matching funds provided from outside sources (government and industry) for which complete data are not currently available. Initially, some projects were fully funded through CANMET. For at least five years CANMET funds have been matched by outside funding, with CANMET funds representing no more than 50% of the total project cost. From 1995-98, a total of $287,990 of NBS funds will be invested in biotechnology for the mining environment, and an additional $287,990 for the environment in the fossil fuel industry. Proposals are only considered if the contractor is able to commit or obtain from industry at least equal funding. Amounts shown in the table are included in Table 6.1.

Table 6.2. CANMET funding for external research projects, 1985-95

Fiscal Year	CANMET Funds Awarded ($000) *	
	Mining Sector	Fossil Fuel Sector
1985-86	199.1	none
1986-87	239.2	none
1987-88	255.7	none
1988-89	289.1	106.7
1989-90	238.7	162.1
1990-91	315.3	351.7
1991-92	201.7	269.8
1992-93	359.0	221.1
1993-94	93.2	226.9
1994-95	95.6	185.0

* matching funds from outside sources not included

6.3 Other R and D Expenditures

Other data on expenditures related to biotechnology in mining are incomplete at his time. No information, therefore, is included on R and D expenditures by industry. Noranda and other companies undertake significant research in this area. In addition, expenditures at universities in Canada are not

included due to the difficulty in obtaining information related specifically to the field. As with industry, university expenditures are likely to be very significant.

In the period 1980 to 1984, the Science Council of British Columbia supported a number of projects related to bioleaching at B.C. Research. Expenditures are shown in Table 6.3.

Table 6.3. B.C. Science Council funding for research projects, 1980-84

Year	Expenditures
1980	80,000
1981	148,550
1982	99,300
1983	65,000
1984	35,000
Total 1980-84	427,850

The large project conducted by Denison Mines in collaboration with CANMET to evaluate in-situ bioleaching at their Elliot lake operations was supported under the IRAP program in the amount of $300-400K. These figures are probably included in the CANMET external funding data.

6.4 Return on Investment

It should be apparent from this chapter that any calculations on the return on investment on biotechnology would be speculative. First, few process are in commercial application. Those that are have not been for a long time or widely applied. In addition, expenditures by the private sector are usually confidential. Second, the accounting of expenditures presented above would need a much greater degree of detail to support this exercise.

A large portion of the benefits that can be foreseen by applying biotechnology are environmental in nature. The value of benefits of processes in this category are a challenge to estimate. However, we know that these benefits are rising since environmental assets are increasing in value because of a perceived scarcity. Also, as environmental standards increase, some of these process could become "best available technology" and be considered valuable.

CHAPTER 7

BARRIERS TO THE USE OF BIOTECHNOLOGY IN THE CANADIAN MINING INDUSTRY

The introduction of any new technology will be subject to barriers preventing or impeding implementation. For very new technologies lacking operational experience and data, many of the barriers preventing adoption will be based mainly on *perceived risks* rather than on *measured risks* which can be quantified on the basis of experience and data. As total risk increases, measured or perceived, financing of projects becomes more difficult and expensive.

Risks associated with a mining project might be summarized into five categories (1): resource, completion, operation, marketing and force majeur. Completion risks and operating risks are the responsibility of the mining company whether financing be corporate or project based. The company will therefore seek to minimize these two as much as possible. Completion and operation risks can be defined as follows:

Completion risk: the economic, technical and legislative risks associated with the construction phase of a project. Questions that can be asked include: What will be the final cost? Is scale up technically feasible? What are the regulations and permitting requirements for the technology?

Operation risk: technical and managerial cost factors contributing to project performance. Questions that can be asked include: Where does the technology apply? What are the boundaries of the technology? Will the process meet performance specifications?

Total risk factors will cause a new or novel technology to be introduced gradually. As users become familiar and experience accumulates, the perceived risk component will be reduced. Measured risk will remain an inherent component, as with all engineering projects, but will be better defined.

In Canada we are seeing a slower rate of adoption of biotechnology in the mining industry compared with the United States, Australia, South Africa, Chile, countries in Europe and elsewhere in the world. The domestic industry has not yet embraced biotechnology to any significant extent. Once a world leader in biotechnology process research and development, we have observed a reduction in effort over the past decade. Significant biotechnological activity and implementation is now taking place in other parts of the world. Are we more risk averse in Canada? Are our tax incentives to introduce new technology too low? Why is biotechnology not being considered when future technology needs are being discussed in many scientific agency reports? Is the Canadian cold climate perceived to be a barrier even if we know it is not for many biotechnologies? Why is the Gibraltar dump leach experience in British Columbia not repeated elsewhere? Have the biotechnology proponents and the mining operators had difficulties in understanding each other? Have the proponents of biotechnology

been unable to provide the industry with engineering data upon which to base proper economic analyses? Are regulations and permitting requirements too onerous?

In the case of biotechnology, the perception of risk is evolving. The pace of evolution cannot be expected to be the same in all places, responding to mineral and project opportunities, tax incentives, the degree of exposure to biotechnology, general mentality, climate, etc. Barriers will come down for specific technologies as the market evaluates if the risk is acceptable for the expected benefit. Benefit and value can go up (price of commodity, environmental pressure or advantage) and/or risk-costs can go down as commercial experience is gained. In this context, with the significant commercialization of STR biooxidation of refractory gold concentrates, we now have a 'show-case' technology. Concerning this technology we can read in the reports of financial observers, "We believe that a new technology, biooxidation, may be the next technical revolution in gold processing" (2). The same source also notes that biohydrometallurgical processes are more environmentally friendly than competing technologies. This message is clear and originates from a source that is credible to those who make management decisions. A specific process and biotechnology in general, by association, is improving its standing as a feasible option. Should we now be looking for barriers or for turning points?

1. Robinson, E.L. 1991. Finance for a cyclical industry. Resource Policy, June, 124-132.
2. Nesbitt Burns. 1995. The Road Ahead, The Nesbitt Burns Gold Mining Conference 1995, Whistler, B.C., Nesbitt Burns, Toronto.

CHAPTER 8

CONCLUSIONS

This report has presented a compilation and analysis of data and information relating to the potential of biotechnology in the Canadian mining industry. Information is specifically presented on: technologies and processes; economic analyses; Canadian mineral reserves; regulations affecting implementation of biotechnology in Canada; research and development expenditures; and barriers to implementation.

Applications of biotechnology are in use or have been proposed for every sector of the industry, in extraction, recovery and environmental control, in both metal mining and fossil fuels. There are a large number of technologies in different stages of development ranging from conceptual to commercial. Notable commercial applications are the biooxidation of sulfide-refractory gold concentrates; thin layer bioleaching of copper ores; dump bioleaching of low grade ores and wastes from copper operations; biological cyanide destruction; the treatment of contaminated groundwater by active sulfate reduction; and limited applications of ecological engineering and wetlands for wastewater remediation. Nearing commercial application is the heap bioleaching of sulfide-refractory gold ores. Numerous other processes have been piloted and proven to be technically viable at that scale. Biotechnology is also used commercially in the oil industry for a number of different applications.

Despite considerable expertise and experience in research, development and engineering, Canada has been slower to adopt biotechnology compared with the United States, South Africa, Chile, Australia, countries in Europe, and elsewhere. To date, commercial scale experience is limited to the uranium bioleaching at Denison's Elliot Lake operations in the 1980's and the current dump bioleach for copper at the Gibraltar Mine in B.C.

It can be concluded from the chapter on the economics of selected biotechnology processes that many of them are economic given a specific context (grade, price, location...). It is no surprise that there is relatively small incremental difference between co-existing processes, weighted or adjusted by their associated risk factor. Processes also have their preferred domain of application. Experience and use give a better appreciation of the niche they occupy in relation to one another.

A stronger trade-off than initially foreseen exists between conventional processes and biotechnology processes in relation to environmental friendliness. The balance of costs, that currently favor biotechnology in specific cases only, are frequently tipped in the favour of biotechnology when a greater emphasis is put on environmental factors. Under such conditions, cleaner effluents would be achievable at lower cost with biotechnology processes than with conventional processes in many cases.

On the other hand, the effect of the introduction of biotechnology processes on mineral reserves is more modest than foreseen. There would be a modest increase in the quantity of metal that can be economically recovered , mainly from increased efficiency from the treatment of low grade or waste material or by substituting an existing process for a more efficient one. Where gains in efficiency can

be made, cutoff grade can be slightly lowered and mining plans modified. However, the introduction of technology that would permit the economic mining of a new class of lower grade deposits in Canada is not indicated.

The aggregate gains in productivity by having the possibility to treat smaller deposit of refractory gold, to scavenge refractory gold dumps and tailings, to circumvent the presence of other metal in gold ore, and to leach copper from dumps, make important reserve increases but not by a large amount. Applications which would minimize environmental cost would make increases larger on a relative scale. If processes for environmental applications are available, it could mean that more production could be maintained rather then being made non-economic because of stricter environmental requirements. This could serve to enlarge reserves as a result of the application of biotechnology.

Given the conclusion that biotechnology has a significant potential for the secondary recovery of values from waste, low grade and tailings materials, it is recommended that the preliminary inventory of quantities of waste rock and tailings presented herein be extended to develop a detailed inventory of metal contents of such materials. Furthermore it is recommended that policy be developed to allow companies which invest and implement technologies to recover values from waste materials to receive reward for the environmental benefits that accrue.

Return on investment for metal extraction by biotechnology can be calculated by comparing expenditures and benefits. Benefits include both the ability to extract metal from otherwise untreatable ore and the differential revenues over those obtainable with conventional technology. Given proper background information, return can be estimated, promoting market driven investment. This means that funding could essentially be non-governmental because benefits are measurable and the decisions to invest is left to industry.

Return on investment for environmental processes using biotechnology could be very large. The benefits in this case would be the sum of private and public benefit. Private benefits include, for example, licencing fees or reduced costs of compliance. These benefits can be measured. The challenge is to determine the value of public benefit. Such benefits are not easily accountable and market driven research will, therefore, not be sufficient to ensure adequate funding for commercialization. In this case, involvement of public funding is justified. In addition, markets are not always farsighted, so that longer term goals should be promoted by public funding policies be they in environment or metal extraction.

The main issues concerning regulation of biotechnology are the impact on the environment and human health associated with the release of microorganisms. A review of regulations affecting the application of biotechnology in Canada indicates that regulations are still under development. Proposed regulations, which are to be integrated into current federal and provincial sectoral legislation will to come into effect in Summer 1995. The regulations will require users, manufacturers or importers of biotechnology products to notify Environment Canada of such use. Likely notification procedures are

described. Notification procedures for processes employing natural organisms are not expected to be unduly onerous.

Barriers to the implementation of biotechnology in the mining industry are associated with the perception of risk. Perception of risk is related to the availability of credible information. Emergence of operating biotechnological plants is acting to reduce perception of risks and a breaking down of barriers. Risk will continue to be re-evaluated downwards as further operating experience and data accumulate.

APPENDIX I

BIOTECHNOLOGY COMPONENT OF THE DOMESTIC SUBSTANCES LIST

MASKED NAME REGULATIONS

GOVERNMENT NOTICES

DEPARTMENT OF THE ENVIRONMENT

BIOTECHNOLOGY COMPONENT OF THE DOMESTIC SUBSTANCES LIST—PROVISIONAL LIST

Purpose

The *Canadian Environmental Protection Act* (CEPA) was proclaimed on June 30, 1988. Subsection 25(1) of the Act requires the Minister of the Environment to compile a list of substances "to be known as the Domestic Substances List" which specifies "all substances that the Minister is satisfied were, between January 1, 1984 and December 31, 1986, (*a*) manufactured in or imported into Canada by any person in a quantity of not less than 100 kg in any one calendar year; or (*b*) in Canadian commerce or used for commercial manufacturing purposes in Canada".

The *Domestic Substances List* (DSL) identifies substances which, for the purposes of the CEPA, are not subject to the requirements of the Regulations respecting Notification of Substances New to Canada (*New Substances Notification Regulations*), which will be implemented under section 32 of CEPA. The DSL defines existing substances for the purposes of the CEPA and is the sole basis for determining whether a substance is "existing" or "new" to Canada. Toxicity is not a criterion for inclusion on the List and, consequently, the DSL should not be viewed as a listing of toxic substances.

Substances that are not on the DSL and that are subject to the *New Substances Notification Regulations*, will require notification and assessment before they can be manufactured in or imported into Canada. The information required from importers and manufacturers will be specified by information requirements in the Regulations. Information requirements on such substances will allow the assessment of the potential to adversely impact on the environment and human health and implementation of appropriate regulatory control if necessary. Information requirements for biotechnology products will be prescribed in the *New Substances Notification Regulations for Biotechnology Products* to be enacted under section 32 of CEPA. These Regulations are currently under development and scheduled for publication in 1994.

The DSL for chemicals and polymers was published as a Supplement to the *Canada Gazette*, Part I, pages 1 to 916, on January 26, 1991. At the time of this publication, consultations were underway between the Federal Government and interested parties concerning the Regulations for biotechnology products under the purview of the CEPA. Consequently, biotechnology products were not included in the 1991 publication.

The Department of the Environment is now in the process of compiling a biotechnology component of the DSL. For the purposes of listing these substances, a biotechnology product is defined as "a substance manufactured through the application of biotechnology". As a first step, the Department of the Environment is accepting nominations

AVIS DU GOUVERNEMENT

MINISTÈRE DE L'ENVIRONNEMENT

LISTE INTÉRIEURE DES SUBSTANCES, VOLET BIOTECHNOLOGIE — LISTE PROVISOIRE

Objet

La *Loi canadienne sur la protection de l'environnement* (LCPE) a été adoptée le 30 juin 1988. Le paragraphe 25(1) de la Loi exige que le ministre de l'Environnement établisse «une liste de substances, dénommée Liste intérieure des substances, qui énumère toutes les substances qu'il estime avoir été, entre le 1[er] janvier 1984 et le 31 décembre 1986 : *a*) soit fabriquées ou importées au Canada par une personne en des quantités d'au moins 100 kg au cours d'une année; *b*) soit commercialisées ou utilisées à des fins de fabrication commerciale au Canada.»

La *Liste intérieure des substances* (LIS) énumère des substances qui, aux fins de la LCPE, ne sont pas assujetties aux exigences du règlement concernant la fourniture de renseignements sur les substances nouvelles (*Règlement sur les renseignements concernant les substances nouvelles*) qui entrera en vigueur en vertu de l'article 32 de la LCPE. La LIS définit ce qu'est une substance existante au sens de la Loi et constitue le seul document qui permet de déterminer si une substance est «existante» ou «nouvelle» au Canada. La toxicité n'étant pas un critère pour l'établissement de la liste, la LIS ne devrait pas être considérée comme une liste de substances toxiques.

Les substances non énumérées dans la LIS et non assujetties au *Règlement sur les renseignements concernant les substances nouvelles*, devront faire l'objet d'un préavis et d'une évaluation avant leur fabrication ou leur importation au Canada. La documentation requise des importateurs et des fabricants sera précisée à titre de renseignements réglementaires dans le Règlement. Les renseignements réglementaires sur de telles substances permettront l'évaluation des risques d'effets nuisibles pour l'environnement et la santé humaine et la mise en œuvre des contrôles réglementaires appropriés si nécessaire. Les renseignements réglementaires seront prescrits dans le *Règlement sur les renseignements concernant les substances nouvelles relativement aux produits de la biotechnologie* qui sera appliqué en vertu de l'article 32 de la LCPE. La publication de ce règlement, actuellement en cours d'élaboration, est prévue en 1994.

La LIS, volet produits chimiques et polymères, a été publiée en supplément de la Partie I de la *Gazette du Canada*, pages 1 à 916, le 26 janvier 1991. Lors de la publication de ce document, des consultations entre le gouvernement fédéral et les intervenants concernés étaient en cours au sujet du règlement concernant les produits de la biotechnologie, dans le cadre de la LCPE. Conséquemment, les produits de la biotechnologie n'ont pas été inclus dans la LIS publiée en janvier 1991.

Le ministère de l'Environnement compile présentement un volet biotechnologie de la LIS. Un produit de la biotechnologie est défini comme suit : «un produit fabriqué suite à l'application de la biotechnologie». Le ministère de l'Environnement accepte lors de cette première étape, les micro-organismes, et les substances produites, comme

for microorganisms, or substances, such as enzymes, produced by microorganisms and other organisms. The eligibility criteria specified under subsection 25(1) of the CEPA, specify those substances eligible for the DSL.

Compilation of the Provisional DSL

During Phase I, Canadian manufacturers and importers of biotechnology products replied to the publication of an advisory note in the *Canada Gazette*, Part I, pages 1606 to 1608, on June 13, 1992. This note informed Canadian manufacturers and importers of eligible biotechnology products that the Department of the Environment was undertaking the preparation of the biotechnology component of the DSL and guidelines for reporting biotechnology products for the DSL were available. A second advisory note was published in the *Canada Gazette*, Part I, pages 1186 to 1189, on April 24, 1993. This notice offered Canadian importers and manufacturers a second opportunity to obtain information on reporting biotechnology products for the DSL.

Substances nominated in Phase I have been evaluated by the Department of the Environment to determine consistency with the eligibility criteria specified in CEPA, as well as the completeness of complementary information (for example substance use, sites of manufacture, quantities) required as part of the reporting process. Some substances were rejected for the DSL as a consequence of errors, omissions or inconsistencies in the data. All the substances judged consistent with the eligibility criteria are documented in the Provisional List of Biotechnology Component of the DSL included below.

Phase II begins with this publication. Canadian manufacturers and importers are asked to review the Provisional List, to nominate additional substances and to comment on inaccuracies. This list will then be revised to include those new nominations, which are consistent with the statutory criteria.

Format and Use of the Provisional DSL

Microorganisms

Specific Substance Name for organisms: The specific Substance Name is the item of information which is used to list nominated substances. For the purposes of the biotechnology component of the DSL, any of the information respecting the identification, characteristics and use of a microorganism may be used to formulate a Specific Substance Name which provides a unique description for its entry on the DSL.

Name: Where a taxonomic identification is provided, this identification includes a valid species name. Identification follows the International Code of Nomenclature and standard taxonomic sources, and is consistent with modern methods used in microbial taxonomy. Where the taxonomic name is described, the authority or the identifier may be listed. Monographs, references, synonyms, and any substantiating evidence may also be listed. The strain designation for the microorganism used in the laboratory of the manufacturer may also be listed.

les enzymes, produites par les micro-organismes et par d'autres organismes. Les critères d'admissibilité précisés au paragraphe 25(1) de la LCPE exigent l'ajout des substances biotechnologiques à la LIS.

Établissement de la LIS provisoire

Pendant la phase I, les fabricants et les importateurs canadiens de produits de la biotechnologie ont répondu à la note d'information publiée dans la Partie I de la *Gazette du Canada*, pages 1606 à 1608, le 13 juin 1992. Cette note avait pour objet d'informer les fabricants et les importateurs canadiens de produits de la biotechnologie admissibles que le ministère de l'Environnement était en train de préparer un volet biotechnologie de la LIS et qu'ils pouvaient se procurer les lignes directrices pour la LIS. Une deuxième note d'information a été publiée dans la Partie I de la *Gazette du Canada*, pages 1186 à 1189, le 24 avril 1993. Cette note avait pour objet de donner une deuxième occasion aux fabricants et aux importateurs canadiens de demander un exemplaire des lignes directrices pour la LIS, volet biotechnologie.

Les substances mises en candidature pendant la phase I ont été évaluées par le ministère de l'Environnement qui a vérifié si elles remplissaient les critères stipulés dans la LCPE et si les renseignements réglementaires complémentaires fournis dans le cadre de la procédure de rapport étaient complets (par exemple, l'utilisation de la substance, les lieux de fabrication, les quantités). Certaines substances ont été rejetées de la LIS à la suite d'erreurs, d'omissions ou d'incohérences dans les données. Toutes les substances satisfaisant aux critères d'admissibilité sont présentées dans la Liste provisoire du volet biotechnologie de la LIS ci-incluse.

La phase II débute avec la publication de cette liste. On demande aux fabricants et aux importateurs canadiens d'examiner la liste provisoire, afin de mettre en candidature des substances supplémentaires et de formuler des commentaires relativement à d'éventuelles inexactitudes. On modifiera alors cette liste en y incluant les nouvelles substances mises en candidature qui satisfont aux critères statutaires.

Présentation et utilisation de la LIS provisoire

Micro-organismes

Nom particulier de la substance pour les organismes : Le nom particulier de la substance est le renseignement utilisé pour énumérer les substances mises en candidature. En ce qui a trait au volet biotechnologie de la LIS, tout renseignement sur l'identification, les caractéristiques et l'utilisation d'un micro-organisme peut être utilisé pour former un nom particulier de substance qui donne une description unique pour son inscription sur la LIS.

Nom : Lorsqu'une identification taxonomique est fournie, celle-ci inclut un nom d'espèce valable. L'identification est conforme au Code international de nomenclature et aux sources taxonomiques normalisées, et elle cadre avec les méthodes modernes employées en taxonomie microbienne. Lorsque le nom taxonomique est décrit, on peut indiquer l'autorité ou l'identificateur. On peut aussi énumérer les monographies, références, synonymes et toute preuve à l'appui. On peut aussi indiquer la désignation de la souche du micro-organisme utilisé dans le laboratoire de l'entreprise.

Synonyms: Include trade names, as well as common, scientific, binomial, alternative and superseded names for microorganisms, separated from the specific name and from one another with semicolons.

Source: Includes culture collection number, original isolator, and original location where the microorganism was isolated.

History: Includes historical record of product development, including isolation procedures, selection procedures, developmental procedures, genetic modifications, culturing procedures, i.e., every step in developing the organism from its original isolation through to the final product.

Characteristics: Characteristics may include a description of ranges and optima for environmental parameters such as pH, temperature, salinity, oxygen and nutrient requirements pertaining to growth, survival and replication of the microorganism. The information may also include a description of the life cycle or morphology of the microorganism, its ability to produce toxins, the presence of specific resistance factors, the presence of extrachromosomal genetic elements and mobile genetic elements. Spore forming ability or other means to survive environmental stresses may also be listed. Results of testing using "Biolog", "API" or any other automated identification systems may also be included.

Use: Use includes application of the microorganism to a specific process or function and the conditions of use.

Other Information: Other information includes data respecting quality control measures used during manufacturing.

Substances produced from microorganisms and other organisms

Names: Only a single English and a single French name are provided for each substance on the DSL. Synonyms, trade names and submitter names have not been included. A substance may be marketed under a variety of names. The absence of a particular descriptive name from the DSL does not mean that the substance is not included on the List.

CAS Registry Number: A CAS Registry Number will be assigned to each individual entry for the final publication of the biotechnology component of the DSL. The CAS Registry Number is not included in this preliminary listing.

Enzyme Names: Enzyme names listed are based on their function. Enzymes are identified using the exact name of the substance established in accordance with the nomenclature rules of the International Union of Pure and Applied Chemistry (IUPAC).

Source Organism: The taxonomic name for the organism from which the substance was produced is provided. The identification includes at minimum the genus and species level.

EC or IUB Number: For a substance with catalytic activity such as an enzyme, the *International Union of Biochemistry* number (IUB number) is included, if available. The IUB

Synonymes : Comprennent les noms commerciaux, ainsi que les noms communs, scientifiques, binomiaux, autres noms des micro-organismes en les séparant entre eux, ainsi que du nom particulier de la substance, par des points-virgules.

Source : Comprend le numéro de collection de culture, l'isolateur original et l'emplacement où le micro-organisme a été isolé à l'origine.

Historique : Comprend le dossier de l'historique du développement du produit, notamment les méthodes d'isolation, de sélection et de développement, les modifications génétiques, les procédures de culture, soient toutes les étapes du développement de l'organisme, depuis son isolation première jusqu'au produit final.

Caractéristiques : Les caractéristiques peuvent inclure une description de la fourchette et de la valeur optimale des paramètres environnementaux comme le pH, la température, la salinité, les exigences en oxygène et en éléments nutritifs pour la croissance, la survie et la réplication du micro-organisme. Les renseignements peuvent aussi inclure une description du cycle de vie ou de la morphologie du micro-organisme, sa capacité de production de toxines, la présence de facteurs particuliers de résistance, celle d'éléments génétiques extra-chromosomiques et d'éléments génétiques mobiles. On peut aussi indiquer la capacité de former des spores ou d'autres moyens de survivre aux pressions environnementales. Inclure les résultats des essais à l'aide de «Biolog» d'«API» ou de tout autre système d'identification informatique.

Utilisation : L'utilisation comprend l'application du micro-organisme à un processus ou à une fonction précis, ainsi que les conditions d'utilisation.

Autres renseignements : D'autres renseignements comprennent les données relatives aux mesures de contrôle de la qualité en vigueur pendant la fabrication.

Substances produites par les micro-organismes et par d'autres organismes

Noms : Il est à noter qu'un seul nom français et un seul nom anglais sont associés à chaque substance sur la LIS. Les synonymes, les noms commerciaux ainsi que les noms spécifiques aux déclarants ne sont pas inclus. Une substance peut se retrouver commercialisée sous une panoplie de noms. L'absence d'un nom particulier sur la LIS ne signifie pas que la substance ne figure pas sur la Liste.

Numéro de registre du CAS : Un numéro de registre du Chemical Abstracts Service (CAS) sera assigné à chaque entrée de la publication finale de la composante des produits de la biotechnologie de la LIS. Toutefois, le numéro de registre du CAS ne figure pas sur la liste provisoire.

Dénomination de l'enzyme : La dénomination de l'enzyme est basée sur sa fonction. Les enzymes sont nommées en utilisant la dénomination exacte établie conformément aux règles de nomenclature de l'Union internationale de chimie pure et appliquée (UICPA).

Source de l'organisme : Le nom taxonomique de l'organisme à partir duquel la substance est produite, est fourni. L'identification de l'organisme inclut, à tout le moins, le genre et l'espèce.

Numéro de l'EC ou de l'UIB : Pour une substance possédant une activité catalytique telle qu'une enzyme, le numéro de l'*Union internationale de biochimie* (n° de l'UIB), sera inclus

number or Enzyme Commission (EC) designation is a four-figure set in which the first figure denotes one of the six main classes of catalytic substances based on the reaction catalyzed; the second and third figures indicate subclasses, and the fourth figure is the serial number of the catalytic substance in its subclass.

Amino Acid Sequence: The amino acid sequence of the protein part of the enzyme is provided, if available.

Unknown or Variable Composition, Complex Reaction Products and Biological Materials (UVCB) Substances: For UVCB substances, the listing includes a supporting substance definition. This definition may include process information, information on possible contaminants, purification steps and any type of modification.

Naturally Occurring Substances: Substances occurring in nature, for the purposes of the DSL, are defined as (1) naturally occurring, and either (2) unprocessed or processed only by manual, mechanical or gravitational means; by dissolution in water; by flotation; or by heating solely to remove water; or (3) extracted from air by any means. All substances falling within this definition are automatically deemed to be on the DSL although they have not been listed individually. The criteria for substances occurring in nature limits inclusion only to those substances derived from nature (including the land, w[illegible] atmosphere and life forms which naturally inhabit the ea[illegible] by the means specified. The interpretation of the criteria is literal and strict. For example, distillation is not considered a mechanical process, and dissolution in solvents other than water also does not fall within this definition. Some substances considered naturally occurring according to this definition may be included on the DSL, if they were manufactured or prepared in a manner not falling within the definitional criteria.

Information and Assistance

For information on the Domestic Substances List, individuals may contact the Department of the Environment at: New Substances Notification, Commercial Chemicals Branch, Department of the Environment, Place Vincent Massey, 14th Floor, 351 Saint-Joseph Boulevard, Hull, Quebec K1A 0H3, 1-800-567-1999 (Toll Free Number), 1-819-953-7155 (Telefax).

It should be noted that the schedule for reporting substances for the biotechnology component of the DSL has been amended. Phase II reporting for manufacturers, importers and users of biotechnology products, will commence on publication of this notice and terminate 90 days later. This period also provides an opportunity for the review and provision of corrections on this Provisional List. The updated biotechnology component of the DSL will be published in the *Canada Gazette* in the spring of 1994.

October 28, 1993

JOHN BUCCINI
Director
Commercial Chemicals Branch

s'il est disponible. Le numéro de l'UIB ou le numéro de l'«Enzyme Commission» (EC) est un numéro à quatre composantes pour lequel la première représente une des six classes principales de substances catalytiques obtenues par catalyse réactionnelle. Les deuxième et troisième composantes représentent des sous-classes de substances catalytiques, tandis que la quatrième correspond au numéro de série de la substance catalytique à l'intérieur de la sous-classe.

Séquence d'acides aminés : La séquence d'acides aminés de la partie protéique de l'enzyme est donnée si elle est disponible.

Substances «Unknown or Variable Composition, Complex Reaction Products and Biological Materials (UVCB)» : Les dénominations de substances UVCB sont suivies d'une définition. Cette définition peut inclure des renseignements sur le procédé de fabrication, sur les contaminants possibles, sur les étapes de purification, ainsi que sur tout type de modification.

Substances existant à l'état naturel : À l'intention de l'établissement de la LIS, les substances existant dans la nature en tant que telles sont définies comme suit : (1) existant naturellement, et soit (2) non traitées ou traitées uniquement par des procédés manuels ou mécaniques ou par gravité, par dissolution dans l'eau, par flottation ou par chauffage à la seule fin d'éliminer l'eau; soit (3) extraites de l'air par tout procédé. Quoique non inscrite individuellement, toute substance se conformant à cette définition, sera automatiquement jugée comme figurant sur la LIS. Le critère pour les substances existant à l'état naturel s'applique seulement aux substances dérivées de la nature (incluant la terre, l'eau, l'atmosphère et toute espèce vivante qui habite naturellement la terre) par les moyens précisés. Les critères seront appliqués strictement et à la lettre. Une distillation, par exemple, n'est pas considérée comme un traitement mécanique et une dissolution dans un solvant autre que l'eau n'entre pas dans cette définition. Selon cette définition, certaines substances considérées comme existant à l'état naturel, pourraient être incluses dans la LIS si elles sont fabriquées ou préparées d'une façon qui ne répond pas au critère de la définition.

Renseignements et assistance

Pour plus de renseignements au sujet de la Liste intérieure des substances, on peut communiquer avec le ministère de l'Environnement à l'adresse suivante : Déclaration des substances nouvelles, Direction des produits chimiques commerciaux, Ministère de l'Environnement, Place Vincent Massey, 14e étage, 351, boulevard Saint-Joseph, Hull (Québec) K1A 0H3, 1-800-567-1999 (numéro sans frais), 1-819-953-7155 (télécopieur).

Veuillez noter que le calendrier de production des déclarations sur les substances destinées à la LIS, volet biotechnologie, est le suivant. La période de déclaration, phase II, pour les fabricants, les importateurs et les utilisateurs débutera dès la publication de cet avis et se terminera 90 jours plus tard. Cette période offre aussi la possibilité de réviser et de corriger la liste provisoire. La mise à jour de la LIS, volet biotechnologie, sera publiée dans la *Gazette du Canada*, au printemps 1994.

Le 28 octobre 1993

Le directeur
Direction des produits chimiques commerciaux
JOHN BUCCINI

PROVISIONAL LIST OF BIOTECHNOLOGY COMPONENT OF THE DOMESTIC SUBSTANCES LIST

Microorganisms

Name: *Saccharomyces cerevisiae*

Source: Isolated from fermentation process (grape pulp or dough).

History: Propagated in YEPD Agar (yeast extract, peptone, dextrose) and preserved in liquid nitrogen. The yeast is produced through a fermentation process using molasses as a sugar source.

Characteristics: Fermentation of glucose. Variable fermentation of galactose, sucrose, maltose and trehalose. No fermentation of lactose. Assimilation of glucose. Variable assimilation of galactose, sucrose, maltose and trehalose. No assimilation of lactose, nitrates, ethylamine•HCl (ethylamine hydrochloride) or cadaverine•2HCl (1,5-pentanediamine, dihydrochloride). No growth in the presence of 100 parts per million cycloheximide.

Use: Used in bread making, fermented beverages and animal feed.

Substances produced from microorganisms and other organisms

Amylase, α-, from ***Aspergillus oryzae***, E.C. 3.2.1.1

Amylase, α-, from ***Bacillus amyloliquefaciens***, E.C. 3.2.1.1

Amylase, α-, from ***Bacillus licheniformis***, E.C. 3.2.1.1

Amylase, gluco-, from ***Aspergillus niger***, E.C. 3.2.1.3

Amylase, gluco-, from ***Rhizopus oryzae***, E.C. 3.2.1.3

Galactosidase, β-, from ***Kluyveromyces marxianus***, E.C. 3.2.1.23

Lipase, triacylglycerol, from ***Rhizopus oryzae***, E.C. 3.1.1.3

Polygalacturonase, from ***Aspergillus japonicus var. aculeatus***, E.C. 3.2.1.15

Polygalacturonase, from ***Aspergillus niger***, E.C. 3.2.1.15

Torula sp., dried

[47-1-o]

LISTE INTÉRIEURE DES SUBSTANCES, VOLET BIOTECHNOLOGIE

Micro-organismes

Nom : *Saccharomyces cerevisiae*

Source : Isolée de levain en fermentation (raisin, pulpe ou pâte).

Historique : Propagée sur Agar YEPD (yeast extract, peptone, dextrose) et conservée en azote liquide. Levures fabriquées par un procédé de fermentation utilisant la mélasse comme source de sucre.

Caractéristiques : Fermentation de glucose. Fermentation variable de galactose, sucrose, maltose et tréhalose. Absence de fermentation de lactose. Assimilation de glucose. Assimilation variable de galactose, sucrose, maltose et de tréhalose. Absence d'assimilation de lactose, nitrates, d'éthylamine•HCl (éthylamine hydrochloride) et de cadavérine•2HCl (1,5-pentanediamine, dihydrochloride). Absence de croissance en présence de 100 parties par million de cycloheximide.

Utilisation : Utilisée dans la fabrication de pain, de boissons fermentées et pour l'alimentation animale.

Substances produites par les micro-organismes et par d'autres organismes

α-Amylase d'*Aspergillus oryzæ*, E.C. 3.2.1.1

α-Amylase de *Bacillus amyloliquefaciens*, E.C. 3.2.1.1

α-Amylase de *Bacillus licheniformis*, E.C. 3.2.1.1

gluco-Amylase d'*Aspergillus niger*, E.C. 3.2.1.3

gluco-Amylase de *Rhizopus oryzæ*, E.C. 3.2.1.3

β-Galactosidase de *kluyveromyces marxianus*, E.C. 3.2.1.23

Lypose triacylglycérique de *Rhizopus oryzæ*, E.C. 3.1.1.3

Polygalacturonase d'*Aspergillus japonicus var. aculeatus*, E.C. 3.2.1.15

Polygalacturonase d'*Aspergillus niger*, E.C. 3.2.1.15

***Torula sp.* déshydratée**

[47-1-o]

DEPARTMENT OF THE ENVIRONMENT

CANADIAN ENVIRONMENTAL PROTECTION ACT

Notice is hereby given that, pursuant to the provisions of Part VI of the *Canadian Environmental Protection Act*, Permit No. 4543-2-03099 is approved.

1. *Permittee*: Westview Dredging Ltd., Southern Georgia Strait, B.C.

2. *Type of Permit*: To dump or load dredged material.

3. *Term of Permit*: Permit is valid from November 23, 1993 to November 22, 1994.

4. *Loading Site(s)* [Refer to condition 11]:

(*a*) Various approved sites on the southeast portion of Vancouver Island at approximately 49°10.00′ N., 123°56.00′ W;

MINISTÈRE DE L'ENVIRONNEMENT

LOI CANADIENNE SUR LA PROTECTION DE L'ENVIRONNEMENT

Avis est par les présentes donné que le permis n° 4543-2-03099 est approuvé conformément aux dispositions de la partie VI de la *Loi canadienne sur la protection de l'environnement*.

1. *Titulaire* : Westview Dredging Ltée, partie sud du détroit de Géorgie (C.-B.).

2. *Type de permis* : Permis d'immerger ou de charger des matières draguées.

3. *Durée du permis* : Le permis est valide du 23 novembre 1993 au 22 novembre 1994.

4. *Lieu(x) de chargement* (Voir la condition 11) :

a) Divers lieux approuvés dans la partie sud-est de l'île de Vancouver à environ 49°10.00′ N., 123°56.00′ O.;

Registration
SOR/94-261 24 March, 1994

CANADIAN ENVIRONMENTAL PROTECTION ACT

Masked Name Regulations

P.C. 1994-486 24 March, 1994

His Excellency the Governor General in Council, on the recommendation of the Minister of the Environment and the Minister of National Health and Welfare, pursuant to subsection 32(1) of the Canadian Environmental Protection Act*, is pleased hereby to make the annexed Regulations respecting the masking of names of substances to prevent the disclosure of confidential information.

REGULATIONS RESPECTING THE MASKING OF NAMES OF SUBSTANCES TO PREVENT THE DISCLOSURE OF CONFIDENTIAL INFORMATION

Short Title

1. These Regulations may be cited as the *Masked Name Regulations*.

Interpretation

2. In these Regulations,

"Act" means the *Canadian Environmental Protection Act*; (*Loi*)

"chemical group" means an arrangement of bonded atoms that is a portion of a molecule and that possesses a name consisting of a non-composite radical term established in accordance with the chemical nomenclature rules of the International Union of Pure and Applied Chemistry or the Chemical Abstracts Service; (*groupe chimique*)

"locant" means a numeral or Greek or Roman letter used in the name of a substance to indicate the positions of unsaturated bonds or attachments of chemical groups in a molecule; (*symbole indicateur de position*)

"masked name" means a name determined in accordance with section 3 that conceals the explicit chemical or biological name of a substance without misrepresenting the generic identity of the substance; (*dénomination maquillée*)

"multiplicative prefix" means a prefix that describes the number of identical chemical groups in a chemical substance; (*préfixe multiplicatif*)

"non-descriptive term" means a term used in the masked name of a substance, in place of a distinctive element of

* R.S., c. 16 (4th Supp.)

Enregistrement
DORS/94-261 24 mars 1994

LOI CANADIENNE SUR LA PROTECTION DE L'ENVIRONNEMENT

Règlement sur les dénominations maquillées

C.P. 1994-486 24 mars 1994

Sur recommandation de la ministre de l'Environnement et de la ministre de la Santé nationale et du Bien-être social et en vertu du paragraphe 32(1) de la Loi canadienne sur la protection de l'environnement*, il plaît à Son Excellence le Gouverneur général en conseil de prendre le Règlement prévoyant le maquillage des noms de substances afin d'empêcher la divulgation de renseignements confidentiels, ci-après.

RÈGLEMENT PRÉVOYANT LE MAQUILLAGE DES NOMS DE SUBSTANCES AFIN D'EMPÊCHER LA DIVULGATION DE RENSEIGNEMENTS CONFIDENTIELS

Titre abrégé

1. *Règlement sur les dénominations maquillées*.

Définitions

2. Les définitions qui suivent s'appliquent au présent règlement.

« dénomination maquillée » Nom établi conformément à l'article 3 qui masque la dénomination chimique ou biologique d'une substance sans en dénaturer l'identité générique. (*masked name*)

« groupe chimique » Groupe d'atomes liés entre eux constituant une partie d'une molécule et dont le nom est un radical non combiné établi conformément aux règles de nomenclature de l'Union internationale de chimie pure et appliquée ou du Chemical Abstracts Service. (*chemical group*)

« Loi » La *Loi canadienne sur la protection de l'environnement*. (*Act*)

« préfixe multiplicatif » Préfixe indiquant le nombre de groupes chimiques identiques dans une substance chimique. (*multiplicative prefix*)

« structure parentale » Chaîne principale ou système cyclique dont provient la dénomination chimique ou une partie de celle-ci. (*parent structure*)

« symbole indicateur de position » Chiffre ou caractère grec ou romain utilisés dans le nom d'une substance pour indiquer la position des liaisons d'insaturation ou la position des groupes chimiques dans une molécule. (*locant*)

* L.R., ch. 16 (4e suppl.)

the explicit chemical or biological name, that does not misrepresent the generic identity of the substance; (*terme non descriptif*)

"parent structure" means the principal chain or ring system from which an explicit chemical name or part of an explicit chemical name is derived. (*structure parentale*)

« terme non descriptif » Terme utilisé dans la dénomination maquillée d'une substance qui remplace un élément distinctif de la dénomination chimique ou biologique et qui ne dénature pas l'identité générique de cette substance. (*non-descriptive term*)

Masking

3. (1) For the purposes of section 31 of the Act, the explicit chemical or biological name of a substance shall be masked by

(*a*) replacing a single distinctive element of the name with a non-descriptive term;

(*b*) replacing each of two or more distinctive elements of the name with a non-descriptive term;

(*c*) removing the locants; or

(*d*) removing the locants and replacing each of one or more other distinctive elements with a non-descriptive term.

(2) The number of distinctive elements in an explicit chemical or biological name that are replaced or removed in accordance with subsection (1) shall not exceed the minimum number necessary to ensure confidentiality.

(3) For the purposes of subsection (2), the removal of a stereochemical indicator from an explicit chemical name does not constitute the removal of a distinctive element.

Maquillage

3. (1) Pour l'application de l'article 31 de la Loi, la dénomination chimique ou biologique d'une substance doit être maquillée :

a) soit en remplaçant un seul élément distinctif de la dénomination par un terme non descriptif;

b) soit en remplaçant deux ou plusieurs éléments distinctifs de la dénomination par des termes non descriptifs;

c) soit en supprimant les symboles indicateurs de position;

d) soit en supprimant les symboles indicateurs de position et en remplaçant un ou plusieurs autres éléments distinctifs par des termes non descriptifs.

(2) Le nombre d'éléments distinctifs d'une dénomination chimique ou biologique qui sont remplacés ou supprimés conformément au paragraphe (1) ne doit pas dépasser le nombre minimum nécessaire pour assurer la confidentialité.

(3) Pour l'application du paragraphe (2), la suppression d'un indicateur stéréochimique d'une dénomination chimique ne constitue pas la suppression d'un élément distinctif.

Explicit Chemical Name

4. Subject to section 6, where all or part of the explicit chemical name of a substance can be described with a structural diagram, any of the following is a single distinctive element of that name or part:

(*a*) a locant;

(*b*) a locant and multiplicative prefix that together specify the position and number of a chemical group;

(*c*) the name of a chemical group;

(*d*) the name of the parent structure and the locant of a chemical group bounded by the parent structure; or

(*e*) in the case of a salt, the name and multiplicative prefix of a single cation or anion of the salt.

Dénomination chimique

4. Sous réserve de l'article 6, dans le cas où la totalité ou partie de la dénomination chimique d'une substance peut être identifiée au moyen d'une représentation structurale, chacun des éléments qui suivent ne représente qu'un seul élément distinctif de la totalité ou partie de cette dénomination :

a) un symbole indicateur de position;

b) un symbole indicateur de position et un préfixe multiplicatif qui ensemble précisent la position et le nombre d'un groupe chimique;

c) le nom du groupe chimique;

d) le nom de la structure parentale et le symbole indicateur de position d'un groupe chimique lié à la structure parentale;

e) dans le cas d'un sel, le nom et le préfixe multiplicatif d'un cation ou d'un anion simple du sel.

5. (1) Subject to subsection (2) and section 6, where the explicit chemical name of a substance cannot be described with a structural diagram, either of the following is a single distinctive element of that name:

(*a*) a constituent of the name that describes a complex mixture of a known class of chemicals including any substance that is recorded in the *Chemical Abstracts Chemical Substance Index* as an indefinite or general derivative of a specific chemical substance; or

5. (1) Sous réserve du paragraphe (2) et de l'article 6, dans le cas où la dénomination chimique d'une substance ne peut être identifiée au moyen d'une représentation structurale, chacun des éléments qui suivent ne représente qu'un seul élément distinctif de cette dénomination :

a) une composante de la dénomination qui identifie un mélange complexe d'une catégorie connue de substances chimiques, y compris toute substance enregistrée dans le *Chemical Abstracts Chemical Substance Index* comme dérivé indéfini ou général d'une substance chimique spécifique;

(b) a constituent of the name that describes a complex mixture of an unknown class of chemicals including a substance that is recorded or is capable of being recorded in the *Chemical Abstracts General Subject Index* and can be named only by using descriptive or illustrative terms.

(2) For the purposes of subsection (1), where a part of the explicit chemical name can be described with a structural diagram, the masking of that part shall be carried out in accordance with section 4.

6. Where a substance referred to in section 4 or 5 contains a chemical group that includes a carbon atom possessing more than a single valence, the name of the chemical group shall not be masked where the carbon atom is

(*a*) attached directly to an acyclic carbon atom; or

(*b*) included within a ring system.

7. The name of a parent structure of a substance referred to in section 4 or 5 may be masked only by one of the following non-descriptive terms, as appropriate:

(*a*) alkyl or alkane;

(*b*) alkenyl or alkene;

(*c*) alkynyl or alkyne;

(*d*) carbomonocyclic or carbomonocycle;

(*e*) carbopolycyclic or carbopolycycle;

(*f*) heteromonocyclic or heteromonocycle; or

(*g*) heteropolycyclic or heteropolycycle

Explicit Biological Name

8. Where all or any part of the name of a substance is an explicit biological name, any of the following is a single distinctive element of that explicit biological name:

(*a*) the genus name;

(*b*) the species name;

(*c*) the strain name;

(*d*) the common biological name;

(*e*) the source;

(*f*) the culture history;

(*g*) the phenotypic or genotypic characteristics;

(*h*) the use; or

(*i*) any other pertinent descriptive information.

REGULATORY IMPACT ANALYSIS STATEMENT

(*This statement is not part of the Regulations.*)

Description

The *Confidential Information Regulations*, being made pursuant to the *Canadian Environmental Protection Act* (CEPA), gives to anyone having to provide information to the Minister of the Environment and to the Minister of

b) une composante de la dénomination qui identifie un mélange complexe d'une catégorie inconnue de substances chimiques, y compris une substance enregistrée ou pouvant être enregistrée dans le *Chemical Abstracts General Subject Index* qui ne peut être représentée qu'en termes descriptifs ou illustratifs.

(2) Pour l'application du paragraphe (1), dans le cas où une partie de la dénomination chimique peut être identifiée au moyen d'une représentation structurale, le maquillage de cette partie doit être effectué conformément à l'article 4.

6. Dans le cas où une substance visée aux articles 4 ou 5 comprend un groupe chimique qui renferme un atome de carbone possédant plus d'une valence libre, le nom du groupe chimique ne peut être maquillé si l'atome de carbone :

a) est directement fixé à un atome de carbone acyclique;

b) fait partie d'un système cyclique.

7. Le nom d'une structure parentale d'une substance visée aux articles 4 ou 5 ne peut être maquillé que par l'un des termes non descriptifs suivants, selon le cas :

a) alkyle ou alcane;

b) alcényle ou alcène;

c) alkynyle ou alcyne;

d) carbomonocyclique ou carbomonocycle;

e) carbopolycyclique ou carbopolycycle;

f) hétéromonocyclique ou hétéromonocycle;

g) hétéropolycyclique ou hétéropolycycle.

Dénomination biologique

8. Dans le cas où la totalité ou partie de la dénomination d'une substance constitue une dénomination biologique, chacun des éléments suivants ne représente qu'un seul élément distinctif de cette dénomination biologique :

a) le nom du genre;

b) le nom de l'espèce;

c) le nom de la souche;

d) le nom biologique courant;

e) la source;

f) l'historique de la culture;

g) les caractéristiques phénotypiques ou génotypiques;

h) l'utilisation;

i) tout autre renseignement descriptif pertinent.

RÉSUMÉ DE L'ÉTUDE D'IMPACT DE LA RÉGLEMENTATION

(*Ce résumé ne fait pas partie du règlement.*)

Description

Le *Règlement sur les renseignements confidentiels*, promulgué en vertu de la *Loi canadienne sur la protection de l'environnement* (LCPE), donne à quiconque devant fournir des renseignements au ministre de l'Environnement et au

National Health the opportunity to request in writing that this information be treated as confidential.

Section 31 of the CEPA provides that a substance may be identified by a name determined by regulation in the case where the chemical or biological name would result in the disclosure of confidential business information.

The *Masked Name Regulations*, being made pursuant to paragraph 32(1)(*i*) of the CEPA, prescribes the manner of determining a name for a substance. Therefore, any person who complies with the *Confidential Information Regulations*, and who requests that the designation of a substance be treated as confidential, must refer to the *Masked Name Regulations* in order to comply with the manner of determining a name.

For reasons of uniformity, these Regulations establish no criteria to mask the identity of a substance that the person making the disclosure considers as confidential, and ensure that the published masked name is sufficiently specific to enable the general identification of the substance while still preserving the confidentiality of its exact nature.

Alternatives

No other alternative was considered because there is no other way to comply with the requirements of section 31 of the CEPA.

Costs and Benefits

1. *Costs to the Government*

The regulations will generate additional costs for the Department of the Environment. These costs are estimated to be 0.3 of per person-year, i.e. $15,000 per year, plus estimated operating and maintenance costs of $5,000 per year.

2. *Costs to Industry*

The additional costs to the industry will be a function of the time required to determine adequate designations. It is estimated that these costs will equal one half day's work, which means a maximum cost of $250 por substance. According to the Department of the Environment's estimates, 75 to 100 requests per year are expected, and, therefore, the costs to the industry should be between $18,750 and $25,000.

3. *Benefits*

The main benefit of these Regulations is the protection of the competitive position of companies, at both the national and the international levels, by ensuring that the information they will be required to provide to Ministers will be kept confidential.

ministre de la Santé nationale, la possibilité de demander par écrit que ces renseignements soient considérés comme confidentiels.

L'article 31 de la LCPE prévoit qu'une substance puisse être identifiée par un nom déterminé par règlement, dans le cas où la dénomination chimique ou biologique aboutirait à la divulgation de renseignements professionnels confidentiels.

Le *Règlement sur la dénomination maquillée* est pris en vertu de l'alinéa 32(1)*i*) de la LCPE et fixe le mode de dénomination d'une substance. Ainsi, quiconque se soumet au *Règlement sur les renseignements confidentiels*, et qui demande que la dénomination d'une substance soit considérée comme confidentielle, doit se référer au *Règlement sur la dénomination maquillée* afin de respecter le mode de dénomination.

Pour des raisons d'uniformité, ce règlement établit les critères à suivre afin de camoufler l'identité d'une substance que le déclarant considère comme confidentielle et veiller à ce que les dénominations maquillées soient suffisamment spécifiques pour permettre une identification générale de la substance tout en préservant le caractère confidentiel de sa nature exacte.

Solutions envisagées

Aucune autre alternative n'a été envisagée parce qu'il n'existe pas d'autre solution pour répondre aux exigences prévues par l'article 31 de la LCPE.

Coûts et avantages

1. *Coûts pour le Gouvernement*

Ce règlement engendra des coûts additionnels pour le ministère de l'Environnement. Ces coûts sont évalués à l'usage de 0,3 d'une personne-année, ce qui représente 15 000 $ par année, ainsi qu'à des dépenses d'opération et d'entretien estimées à 5 000 $ annuellement.

2. *Coûts pour l'entreprise*

Les coûts additionnels pour l'entreprise seront associées au temps nécessaire pour déterminer la dénomination adéquate. On estime que ces coûts s'élèveront à l'équivalent d'une demi journée de travail, ce qui représente un coût maximal de 250 $ par substance. Le ministère de l'Environnement estime qu'il recevra entre 75 et 100 demandes par année, par conséquent, les coûts pour l'entreprise devraient se situer entre 18 750 $ et 25 000 $.

3. *Avantages*

L'avantage principal de ce règlement sera de protéger la position concurrentielle des entreprises, autant au niveau national qu'au niveau international, en leur assurant la confidentialité des renseignements qu'elles auront à fournir au ministère de l'Environnement ainsi qu'au ministère de la Santé nationale et du Bien-être social.

Consultation

The Department of the Environment has forwarded for comments a copy of the regulations to the various stakeholders listed in the appendix to this document. The consultations were held over the period from July 26 to August 17, 1993, inclusive. Following the comments received from the industry, a few minor modifications were made to the regulations.

A notice on the *Confidential Information Disclosure Regulations* was published in the 1993 Federal Regulatory Plan. These proposed regulations included the *Confidential Information Regulations*, as well as the *Masked Name Regulations*. Following the comments received, the proposed *Regulations on Confidential Information Disclosure* was split into two distinct regulations because not all requests for confidentiality involve masking.

Compliance and Enforcement

Since these Regulations are of a strictly administrative nature and since they contain no prohibition provisions, no implementation will be undertaken. Therefore, no inspection will be necessary to check compliance with the regulations.

Any application for masked designation following a request for confidentiality will be checked by the Commercial Chemicals Branch of the Department of the Environment. Such checks will ensure compliance with the requirements of these Regulations.

Any person who receives or obtains, or may access information under the CEPA is bound to comply with security policies applicable to persons who have normal access to, or who use this information, as well as to take the oath of secrecy required of those persons.

Contact

Lawrence Fedoruk
Commercial Chemical Evaluations Branch
Pollution Prevention Directorate
Department of the Environment
Ottawa, Ontario
K1A 0H3
(819) 953-1671

Arthur Sheffield
Economic Analysis Branch
Response Assessment Directorate
Department of the Environment
Ottawa, Ontario
K1A 0H3
(819) 953-1172

Consultation

Le ministère de l'Environnement a fait parvenir aux différents intervenants, listés en annexe du présent document, une copie du Règlement afin d'obtenir leurs commentaires. La période de consultations s'est étendue du 26 juillet au 17 août 1993 inclusivement. Suite aux commentaires reçus de l'industrie, quelques modifications mineures ont été apportées au règlement.

Un préavis sur le *Règlement sur la divulgation de renseignements confidentiels* a été publié dans les Projets de réglementation fédérale 1993. Ce projet de règlement englobait le *Règlement sur la dénomination maquillée* de même que le *Règlement sur les renseignements confidentiels*. Suite à des commentaires reçus, la réglementation proposée sur la *Divulgation de renseignements confidentiels* a été séparé en deux règlements distincts parce que toutes demandes de confidentialité n'implique pas nécessairement le maquillage de la dénomination chimique ou biologique.

Respect et exécution

Puisque ce règlement est strictement de nature administrative et qu'il ne contient aucune clause pouvant entraîner une infraction, aucune mise en application ne sera entreprise. Par conséquent, aucune inspection ne sera nécessaire pour vérifier la conformité au Règlement.

Toute dénomination maquillée proposée suite à une demande de confidentialité fera l'objet d'une vérification par la Direction des Produits chimiques commerciaux du ministère de l'Environnement. Ces vérifications assureront le respect des exigences prévues au présent Règlement.

Quiconque reçoit ou obtient de l'information, ou y a accès, sous le régime de la LCPE est tenu d'observer les consignes de sécurité applicables aux personnes qui y ont normalement accès ou qui l'utilisent, ainsi que de prêter le serment de secret exigé de celles-ci.

Personne-ressources

Lawrence Fedoruk
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Direction générale de la prévention de la pollution
Ministère de l'Environnement
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Arthur Sheffield
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Direction générale de la réaction à l'évaluation
Ministère de l'Environnement
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APPENDIX

BASF Canada Inc.
Monsanto Canada, Inc.
DuPont Canada Inc.
Lever Brothers Ltd.
3M Canada Inc.
Imperial Oil Ltd.
Delmar Chemicals Inc.
Don Kerr Consulting
The Canadian Portland Cement Association
Canadian Pulp & Paper Association
Canadian Electrical Association
Canadian Ceramics Society
Crop Protection Institute of Canada
Society of Plastic Industry of Canada
Canadian Textile Institute
Canadian Manufacturers' Association
Soaps & Detergent Association of Canada
Canadian Petroleum Products Institute
The Mining Association of Canada
Canadian Association of Chemical Distributors
Canadian Environmental Network
Industrial Biotechnology Association of Canada
Adhesives and Sealants Manufacturers' Association of Canada (ASMAC)
The Canadian Chemical Producers' Association
Canadian Paint & Coating Association
Canadian Steel Environmental Association
Ecological & Toxicological Association of the Dyestuffs Manufacturing Industry (ETAD)
Electrical and Electronic Manufacturers' Association
Canadian Manufacturers of Chemical Specialties Association
Canadian Chemical Producers Association
Industry, Science and Technology Canada
Health & Welfare Canada
Canadian Labour Congress
Brunswick Mining & Smelting Corporation Limited
Van waters & Rogers Limited

ANNEXE

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QUEEN'S PRINTER FOR CANADA, OTTAWA, 1994 IMPRIMEUR DE LA REINE POUR LE CANADA, OTTAWA, 1994

APPENDIX II

BIOTECHNOLOGY IN MINING - SOURCE MATERIAL

BIOMINET
The Mineral and Energy Applied Biotechnology Network

BIOMINET, administered through CANMET, is a network of companies, research organizations, and associated agencies interested in applications of biological systems in all aspects of the recovery and processing of minerals and fossil fuel resources. Established in 1983, BIOMINET has a steering committee chaired by a member from industry. A survey in April 1994 indicated 568 members, 498 of them in Canada. A successful Annual meeting has been held every year and a Proceedings of the technical papers published every year except 1984. BIOMINET publishes a regular newsletter (No.29 1994 attached). Copies of the tables of contents of the Proceedings of Annual meetings follow.

NEWS FROM

BIOMINET

THE MINERAL AND ENERGY APPLIED BIOTECHNOLOGY NETWORK — No. 29 1994

BIOLEACHING: *Technology for Today*

It is not too late to register for this session, which will be presented as part of the 24th Annual CIM Hydrometallurgical Meeting, Toronto, on Wednesday, August 24th, 1994 at 2 p.m. Five invited speakers will give presentations.

The Treatment of Refractory Gold Ores and Concentrates by Biooxidation - An Acceptable Alternative? R.W. Lawrence, Department of Mining and Mineral Process Engineering, University of British Columbia, Vancouver, B.C.

Biooxidation of Refractory Gold Ores: The Environmental, Friendly Process. P.C. Van Aswegen, H.J. Marais and J. Broadhurst, Gencor Limited, Marshaltown, South Africa.

The Economics of Gold Biooxidation. J.R. Goode, Kilborn Inc., Beijing, and I. Eljarbo, Kilborn Inc.,Toronto.

Gold and Copper Ore/Concentrate Bioleaching: Commercial Applications and Scale-Up Considerations. C.L. Brierley, VistaTech Partership Limited, Salt Lake City, Utah.

A Cost-Efficiency Computer Model for Assessment of Bioleaching Processes in Tailings Recycling. R. Lebcir, J.L. Sasseville, N. Hammou and J.F. Blais, INRS-Eau, Université du Québec, Ste-Foy, Québec.

For more information contact the BIOMINET Secretariat.

Employing Constructed Wetlands to Remove Contaminants from Waste Waters

Oil sands developments in northeastern Alberta have resulted in the generation of volumes of wastewaters associated with the extraction and upgrading of these petroleum resources. The current process employed by the operating oil sands companies generates high volumes of wastewaters which contain varying

BIOMINET

"The Mineral and Energy Applied Biotechnology Network" (BIOMINET) of the National Biotechnology Networks, formed in an inaugural meeting on October 13-14,1983 has the following defined scope:

"BIOMINET is a network of companies, research organisations and associated agencies interested in applications of biological systems in all aspects of the recovery and processing of minerals and fossil fuel resources."

SUBMISSIONS

The next newsletter is to be published in November, 1994. Anyone wishing to submit news items on research developments, contracts, or articles of interest to BIOMINET members, must submit them to the Secretary no later than Oct. 1st. For further information on BIOMINET, or if you know someone who would like a copy of this newsletter, please notify the Secretary of BIOMINET:

Dr. G.M. Béchard
Secretary, BIOMINET
CANMET,
Natural Resources Canada
555 Booth Street
Ottawa, Ontario
K1A 0G1
Telephone (613) 992-2489
FAX (613) 996-9673

Ce bulletin est aussi disponible en français.

contaminant loads. These contaminants, which originate primarily from the oil sands ore, do include some components which are the result of additives to the extraction and upgrading processes.

Suncor Inc., Oil Sands Group (Suncor) initiated research on the reclamation of both the mined areas, and wastewaters and solids associated with their operation in the 1970s. A detailed research program to investigate the opportunities for application of constructed wetlands systems for the treatment of oil sands contaminated wastewaters began in 1990.

Toxicity Identification Evaluations (TIE) run on representative oil sands wastewaters have confirmed that three potential classes of primary toxic materials are present in these wastewaters including: ammonia, naphthenic acids and phenolic substances.

Suncor established a large field scale wetlands research facility in 1991. This facility includes nine replicate wetlands trenches, each approximately 2m deep x 2m wide at the bottom x 50m in length, with the sides having a slope of approximately 2:1. These trenches, which have a mean slope from inflow to outflow of about 0.5%, were constructed in a level reclaimed area on the Suncor Fort McMurray oil sands lease. The trenches are separated from underlying soils and groundwater by an impermeable barrier. Each of the lined trenches was covered with sand and muskeg and then planted with 60 bulrush culms *(Scirpus validus)* and 300 cattail shoots (*Typhus latifolia*).

Studies conducted at this site since 1991 have prioritized evaluation of the treatment effectiveness of these systems. Three different water types have been fed to the trenches, with three replicate trenches receiving control (non-contaminated waters); three receiving tailings dyke drainage waters; and three receiving tailings recycle waters. Waters have been fed to the trenches during the periods May through September of each of the past two years.

Yearly research efforts at the wetlands trenches include: assessments of hydrology, water quality, water chemistry and sediment chemistry; microbiological assessments; ecological assessments; and toxicological assessments (including both waters and sediments). Additional research efforts undertaken each year include assessments at regional Reference wetlands and collection of weather condition information at the study site.

A special project was conducted during 1993 to assess the potential for bioaccumulation within the biota from the Suncor constructed wetlands systems*. These ecological studies on the wetlands prioritized examination of the uptake of total extractable hydrocarbons are not readily accumulated by plant tissues. However, a weak trend for total extractable hydrocarbon (TEH) within cattail roots and wetlands loading rates was noted. Metal concentrations were generally less in plants sampled from treatment wetlands versus the constructed control and off-site reference wetlands.

Results for TEH uptake by invertebrates showed some difference between treatment and control systems, with the non-treatment systems being significantly lower. Metal uptake analyses were restricted because of sample sizes, but some preliminary indications of differences between treatment and control systems were evident.

For more information on this project:

John R. Gulley
Environmental Research Specialist
Suncor Inc., O.S.G.
Fort McMurray, Alberta,
T9H 3E3

* This was a cost-shared project between Suncor and CANMET, MSL Division.

Performance Evaluation of New Biosorbents for Heavy Metal Removal

Current investigations have indicated an outstanding metal biosorption potential associated with biomass of some ubiquitous brown marine algae, namely *Sagassum* and *Ascophyllum*. These materials can accumulate up to 35% of their dry weight in heavy metals, sometimes even selectively. Recovery of the accumulated metal, can be accomplished from the highly concentrated wash solutions used to regenerate the biosorbent material for reuse. Simple processing of the metal-sorbing biomass materials is necessary to produce durable granules required for pilot biosorption studies. Simultaneously with the development of

new biosorbent materials, research studies are conducted elucidating the mechanism of the biosorbent metal binding. Better understanding of biosorption leads to its optimization and further improvements.

Equilibrium sorption batch tests with one- and two-metal solutions containing Cd, Cu or Zn resulted in two- and three-dimensional sorption isotherm plots, respectively. Their interpretation was used in evaluation of the metal-sorbing performance and assessment of the type of biosorption behavior. While apparently several metal-binding groups exist on biosorbent materials, the metal deposition is competitive to a variable degree. The family of new biosorbents represents a basis for very cost-effective alternative processes for treatment and detoxification of metal-bearing industrial effluents.

This work was presented at the International Union of Microbiological Societies (IUMS) Congress, July 3rd-8th 1994, in Prague.

For more information please contact Dr. B. Voleski, Chemical Engineering, McGill University, 3480 University St., Montreal, H3A 2A7. Tel.: (514) 398-4276. Fax (514) 398-6678.

Newmont Gold's Bioleaching Process

Recent field tests have confirmed the commercial viability of Newmont Gold's patented bioleaching process. The process enables gold to be recovered from low grade sulphidic materials that previously could not be processed economically. An immediate benefit is that the company will be able to add 1.1 million ounces to its reserves at year-end 1994.

In the natural state, sulphides in unoxidized material can block the access of leaching chemicals to the contained gold, preventing gold dissolution and recovery. Most ores near the surface have been naturally oxidized by bacteria as well as by sunlight, water and oxygen. The new process introduces a concentrated culture of bacteria that achieves the same results as nature but in a matter of months. The high density cultures are added to low-grade ore as it is placed on leach pads. The bacteria break down the sulphide crystal structure, allowing the gold to be dissolved and recovered through normal heap leaching processes.

A second bioleach process that is undergoing longer-range development is one aimed at recovering gold from low-grade sulphidic ore that contains active carbon. Such carbon prevents recovery of the gold by adsorbing gold from the solution in which it has been dissolved. Newmont Gold's Nevada pits contain about 2.9 million ounces in low grade material that contains carbon.

(Source: Mining Engineering, April 1994 and CIM Reporter, May 3, 1994.)

Geobiotic Develops Gold Biooxidation Process

Geobiotics (Hayward, CA) is developing a biooxidation process to improve gold recovery from sulphide ores. Laboratory testing was performed with Dakota Mining Corp.'s (Denver, CO) Gilt Edge sulphide ore. Results show gold recovery increasing from 62% to 75-78% due to the enhanced effects of biooxidation.

Indigenous *Thiobacillus ferrooxidans* are responsible for the oxidation and require no nutrients other than the sulphur compounds that occur with the ore. The oxidation is performed in a heap with the effluent being neutralized with limestone. The gold is dissolved in a cyanide solution and is then recovered by precipitation. Pilot studies on 5,000 tons of ore are to be performed in the near future.

(Source: Chemical Engineering, May 1994.)

Special Journal Issue on Bioremediation

The journal "Biodegradation" (Kluwer Academic Publishers) has published a special issue on bioremediation (Volume 4, No. 4, 1993/1994). The guest editorial and seven articles feature some of the typical applications in which bioremediation has been successfully used to cleanup contaminated soils, some recent developments in application technologies and a brief examination of some of the most recent molecular developments which bear on future bioremediation technologies. Unfortunately none of the full scale remediation papers were received in time for inclusion in this edition.

Blackburn *et al.* ("Experimental linkage issues of petroleum site bioremediation") address a num-

ber of physical, chemical, biological, analytical and statistical issues regarding the successful comparison of results between experiments. The lack of reliable field or site linkage at the present time severely hampers commercial-scale operations (Bourquin, p.205). The bioremediation of PCBs is addressed by Tiedje *et al.*, in "Microbial reductive dechlorination of PCBs" and by Anid *et al.*, in "Effect of hydrogen peroxide on the biodegradation of PCBs in anaerobically dechlorinated river sediments". Mikesell *et al.* report on the metabolic diversity of hydrocarbon degraders found in BTEX (benzene, toluene, ethylbenzene, *p*-xylene) contaminated groundwater and conclude that conditions of isolation rather than the substrate used influences the apparent characteristic substrate utilization range of the isolates obtained.

Dolfing *et al.* ("Microbiological aspects of the removal of chlorinated hydrocarbons from air") describe the microbiological principles that influence the biodegradability of chlorinated hydrocarbons and discuss factors which determine the performance of the microorganisms in systems for waste gas treatment. In "Biotechniques for air pollution control", van Groenestijn and Hesselink give an overview of present biological techniques for the treatment of off-gases, which have developed quite rapidly in the EEC, and the techniques that are being developed at the moment. The characteristics, advantages, disadvantages, costs and application areas are discussed and compared. They conclude that biotechniques are efficient and cost effective in treating off-gasses with concentrations of biodegradable contaminants up to 1-5 g/m^3.

The final article, "Molecular diagnostics of polycyclic aromatic hydrocarbon biodegradation in manufactured gas plant soils", by Sanseverino *et al.*, reports on the use of new methods based on molecular biology. These authors determined bioavailability of PAHs in soils using the lux reporter gene and the genetic capacity of these environments was determined with gene probes. The laboratory microcosm data yielded valuable information on the *in situ* population without isolation techniques.

Integration of EMR and Forestry

In 1993, Forestry Canada and EMR were combined to form the new Department of Natural Resources Canada (NRCan). This Department now consists of six science & technology sectors and one Corporate Service Sector. Each is headed by an ADM. The integration allows common concerns in these resource areas, such as trade, environment, sustainable resource development and competitiveness, to be effectively addressed through a single department. The structural integration was largely in place by April, 1994 as planned. Other changes will be phased in over the next 4 years. Legal change in name still requires an Act of Parliament and documentation for this legal change is being prepared.

In the area of Biotechnology there have been some differences in approach in application of this technology between forestry and mining / energy sectors. Discussions are underway to find common ground and, at the same time, ensure the different views within NRCan are adequately represented.

A.J. Oliver
Manager of Environmental Laboratory, CANMET, NRCan.

MEND Reports Related to Biotechnology

Several studies have been funded through the Mine Environment Neutral Drainage (MEND) Program. The following project reports are related to Microbiology, Biotechnology or Biology and available from CANMET. Anyone wishing to obtain copies of the reports summarized in this list should contact:

Mr. T.J. Patel
CANMET
Tel.: (613) 996-9758
Fax: (613) 952-2587.

Prediction

1.14.2
Diversité microbiologique dans la production de drainage minier acide à la halde sud de la Mine Doyon, March 1994.
$30

1.14.2
Development of a Modified MPN Procedure to Enumerate Iron Oxidizing Bacteria, March 1994.
$20

Prevention and Control

2.11.1c
A Preliminary Biological and Geological Assessment of Subaqueous Tailings Disposal in Benson Lake, British Columbia, March 1991.
$25

2.11.2a
Literature Review Report: Possible Means of Evaluating the Biological Effects of Sub-Aqueous Disposal of Mine Tailings, March 1993.
$25

2.44.1
Microbial Plugging of Uranium Mine Tailings to Prevent Acid Mine Drainage - Final Report, December 1992.
$25

Treatment

3.11.1
Treatment of Acidic Seepages Using Wetland Ecology and Microbiology: Overall Program Assessment, July 1993.
$35

3.12.1a
Assessment of Existing Natural Wetlands Affected by Low pH, Metal Contaminated Seepages (Acid Mine Drainage), May 1990.
$25

3.12.2
Panel Wetlands - A Case History of Partially Submerged Pyritic Uranium Tailings Under Water. February 1993.
$35

Monitoring

The following B.C. AMD Task Force reports can be directly purchased from:

Bitech Publishers Ltd.
903-580 Hornby Street
Vancouver, B.C.
V6C 3B6

Telephone: (604) 669-7780
Facsimile: (604) 669-1779

4.7.2
Literature Review for Biological Monitoring of Heavy Metals in Aquatic Environments, September 1990.
$40

Continued p.7

BIOMINET 11th Annual Meeting

The next BIOMINET Annual Meeting will be held in Ottawa at the Westin Hotel on Monday, January 16, 1995. This year's meeting will focus on biotechnology for the mining industry. Presentations will include 3 keynote addresses: Dr. Roger Guay, Laval University, will present the microbiology of acid mine drainage; Dr. Terry Beveridge, University of Guelph, will discuss metal-microbe interactions and Dr. Doug Gould, CANMET, will address the use of rotating biological contactors to treat mining effluents. If you are interested in presenting a technical paper, in particular in areas demonstrating success in the use of biotechnology for the mining industry, please send an abstract to the BIOMINET Secretariat by August 31st. Students in particular are encouraged to submit an abstract and participate in the Student Competition. A detailed program of the meeting will be mailed to all BIOMINET members by September 30th. Papers for the Meeting's Proceedings will be required by October 15th, for publication in time for distribution at the BIOMINET Annual Meeting.

Student Award

Students interested in giving a presentation at the 11th BIOMINET Annual Meeting and contributing to the Meeting's Proceedings are invited to participate in the Student Competition. The Competition is open to full-time registered University students at undergraduate and graduate levels performing work in biotechnology related to the mining sector. BIOMINET will subsidize the travel expenses of the winner(s). The winner(s) will be chosen on both quality and relevance of the abstract to the theme of the BIOMINET meeting. Abstracts must be submitted by September 1st 1994 to Lyne Lortie, CANMET, 555 Booth St., Rm 318, Ottawa, Ontario, K1A 0G1, (613) 992-1596. Proof of full-time registration and the full address of the University must be submitted with the abstract. The winner will be contacted by September 10, 1994. Articles for the Meeting's Proceedings will be due on October 15, 1994.

MEETINGS

4th Annual Symposium on Groundwater and Soil Remediation

September 21-23, 1994
Calgary, Alberta

The Symposium will be held at the Calgary Convention Centre. Presentations will focus on results from projects on basic research, technology development and technology option on groundwater and soil remediation. Presenters will highlight costs for technology options they are investigating.

For further information, please contact Lise Gagné, Environment Canada, Hull, Quebec. Tel.: (819) 953-5227. Fax: (819) 953-7253.

21st Annual Toxicity Workshop

October 2-5, 1994
Sarnia, Ontario

The major topic areas will be: Assessing large ecosystem health, transport and fate; Toxicity testing in decision making - regulation, relevance, remediation; Pathways affecting ecosystems - fate and effects, ecological and human health.

For further information, please contact Marianne Lines at : Tel.:(519) 337-3429 Fax: (519) 337-3486.

Technological Solutions for Pollution Prevention in the Mining and Mineral Processing Industries

January 22-27, 1995
Palm Coast, Florida

Papers are invited on the following sessions: (1) Planning design of mine operations for pollution prevention, and predictive methodologies and technologies. (2) Process modification, including in-process recycling to return wastes or their components for reuse within the operation. (3) Process technology and equipment, including basic production technologies, equipment, or methodologies to reduce or eliminate wastes and fugitive emissions. (4) Plant operations, including management and housekeeping, materials handling, separation procedures and recycling options to reduce or eliminate waste and fugitive emissions. (5) Emerging technologies (including biotechnologies) for pollution prevention and waste minimization. (6) Remining.

For more information, please contact the Engineering Foundation (212) 705-7836 or by Fax (212) 705-7441.

Sudbury '95

Mining and the Environment
Sudbury, Ontario
May 28 - June 1, 1995

Plenary papers describing the issues, approaches taken in different parts of the world and major case studies will be presented. Parallel sessions will follow to communicate advances in specific topic areas. These will include, but will not be limited to:

- Tailings, waste rock and slag management
- Acid mine drainage prevention and control
- New tolls/Old problems
- Rehabilitation methods
- Ground and surface water remediation
- Mining and safety

For more information, please contact R.E.T. (Ross) Bennett, Registration Chairman, Office of Technology Transfer, Laurentian University, Sudbury, Ontario, P3E 2C6. Tel.: (705) 673-6572. Fax: (705) 673-6508.

MEETINGS

Second International Symposium on Waste Processing and Recycling in Mineral and Metallurgical Industries

August 19-23, 1995
Vancouver, British Columbia

The Minerals Science and Engineering Section and the Non-ferrous Pyrometallurgy Section of the Metallurgical Society of CIM, together with The Institution of Mining and Metallurgy (U.K.) are sponsoring the 2nd International Symposium to be held as part of the 34th Annual Conference of Metallurgists. Some of the main topics will include: Waste management and Disposal - Slags, tailings, etc.; Effluent and Internal Recycle Strategies - Processes and plant practice; Resource Recovery and Utilization; Solid/Liquid Separation; Recycling/Treatment of Non-Traditional Feedstocks; Computer Applications, Novel Processes and Design; Rotary Kilns for Waste Recycling; Water - Treatment and Recycling; Waste Gas Treatment; Environmental Implications. The list of topics is not exclusive. Original research and application papers from all areas of mineral and metallurgical industries connected with the main subject matter reflecting contempory interests will be considered. Abstracts (200-300 words) are due by September 30, 1994.

For more information please contact Dr. S.R. Rao (Symposium Chairman), McGill University. Tel.: (514) 398-8492, fax: (514) 398-4492.

25th Annual Hydrometallurgical Meeting. An International Symposium on Leaching-Principles and Practice

October 14-18, 1995
Winnipeg, Manitoba

The Hydrometallurgy Section of the Metallurgical Society of CIM is cordially inviting papers for this symposium.

The following topics will be featured in the technical program: 1) pressure leaching; 2) atmospheric leaching; 3) heap, dump and in situ leaching; 4) biological leaching; and 5) leaching and the environment.

Papers are invited on these and other topics relevant to leaching. Abstract (200-300 words) are due by November 1st, 1994.

For more information, please contact Dr. M.E. Chalkley, Sherrit Inc.
Fort Saskatchewan, Alberta, T8L 3W4.
Tel.:(403) 992-5013.
Fax: (403) 992-5187.

Mining and Environment Research Network

If you would like to receive the Mining and Environment Research Network Newsletter or require information about membership and sponsorship schemes, please contact Dr. Alyson Warhurst, MIMM, Director, Mining and Environment Research Network, Science Policy Research Unit, University of Sussex, Brighton.

4.7.3a
The Effect of Treated Acid Mine Drainage on Stream Macroinvertebrates and Periphytic Algae: An In-Situ Mesocosm Experiment, September 1990.
$27

4.7.3b
Stream Community Responses to a Gradient of Acid Mine Drainage. 1992.
$30

4.7.4
Review of Sediment Monitoring Techniques, prepared for B.C. Acid Mine Drainage Task Force, November 1990.
$36

4.7.6
Use of Paleolimnological Techniques to Assess the Effects of Acid Rock Drainage in British Columbia, 1992.
$30

For a complete list of MEND reports, please contact the MEND Secretariat:

Room 328
555 Booth Street
Ottawa, Ontario
K1A 0G1
Telephone (613) 995-4681
Facsimile (613) 996-9673

Grant Feasby,
Manager
Karen Mailhiot,
Coordinator: Treatment, Technology Transfer
Gilles Tremblay,
Coordinator: Prevention & Control

TABLES OF CONTENTS FOR
PROCEEDINGS OF GENERAL MEETINGS OF

BIOMINET

1985 TO 1994

CONTENTS

SESSION IV: OPEN SESSION

CONTENTS

CONTENTS

CONTENTS

Contents/Table des matières

Contents/Table des matières

CONTENTS/TABLE DES MATIERES

CONTENTS / TABLE DES MATIÈRES

TABLE OF CONTENTS / TABLE DES MATIÈRES

TABLE OF CONTENTS / TABLE DES MATIÈRES

WORKSHOP ON BASIC MICROBIOLOGY FOR THE MINERAL INDUSTRY

R.G.L. McCREADY, V. SANMUGASUNDERAM, and W.D. GOULD

ATELIER DE TRAVAIL SUR LA MICROBIOLOGIE FONDAMENTALE POUR LE COMPTE DE L'INDUSTRIE MINÉRALE

CANMET Special Publication
SP86-7, Vol. 1

BIOTECHNOLOGY BIBLIOGRAPHIES

L.A. BEAUDETTE and/et R.G.L. McCREADY

BIBLIOGRAPHIES DE LA BIOTECHNOLOGIE

CANMET Special Publication
SP 86-2

Publication spéciale du CANMET
SP 86-2

CONTENTS

INTERNATIONAL SYMPOSIA ON BIOHYDROMETALLURGY

An international conference on biohydrometallurgy has been held approximately every two years since 1977. The following pages provide the table of contents for the proceedings of 7 of the Symposia. The 11th Symposia is to be held in November, 1995 in Santiago , Chile.

METALLURGICAL APPLICATIONS *of* BACTERIAL LEACHING *and* RELATED MICROBIOLOGICAL PHENOMENA

Edited by

LAWRENCE E. MURR
ARPAD E. TORMA

John D. Sullivan Center for In-Situ Mining Research,
Department of Metallurgical and Materials Engineering

JAMES A. BRIERLEY

Department of Biology

New Mexico Institute of Mining and Technology
Socorro, New Mexico

ACADEMIC PRESS New York San Francisco London 1978
A Subsidiary of Harcourt Brace Jovanovich, Publishers

Contents

Contents

RECENT PROGRESS IN BIOHYDROMETALLURGY

Edited by

Giovanni Rossi* and Arpad E. Torma**

**Department of Mining and Mineral Dressing, Faculty of Engineering, University of Cagliari, 09100 Cagliari, Italy.*

***John D. Sullivan Center for In-Situ Mining Research, Department of Metallurgical and Materials Engineering, New Mexico Institute of Mining & Technology, Socorro, New Mexico, 87801, U.S.A.*

ASSOCIAZIONE MINERARIA SARDA - 09016 IGLESIAS - ITALY
1983

CONTENTS

SECTION 3: *In-Situ, Heap, Dump and Larger Scale Leaching*

SECTION 4: *Kinetics, Modelling and Scale-up Studies*

SECTION 5: *Waste and Low-Grade Material Bioleaching and Environmental Considerations*

SECTION 6: *Coal and Shale Biodesulfurization*

SECTION 7: *Genetic Engineering of Microorganisms involved in the Biohydrometallurgical Processes*

SECTION 8: *General Topics*

Process Metallurgy 4

FUNDAMENTAL AND APPLIED BIOHYDROMETALLURGY

Proceedings of The Sixth International Symposium on Biohydrometallurgy
Vancouver, B.C., Canada, August 21–24, 1985

Edited by

RICHARD W. LAWRENCE
B.C. Research, Vancouver, B.C., Canada

RICHARD M.R. BRANION
Department of Chemical Engineering, University of British Columbia, Vancouver, B.C., Canada

HANS G. EBNER
Bergbau Forschung GmbH, Essen, Federal Republic of Germany

ELSEVIER
Amsterdam – Oxford – New York – Tokyo 1986

CONTENTS

BioHydroMetallurgy

Proceedings of the International Symposium
Warwick 1987

Edited by

PAUL R. NORRIS
&
DON P. KELLY

S T L

1988

2. CHALCOPYRITE CONCENTRATES

3. PROCESS KINETICS OF CONCENTRATE LEACHING

INTERACTIONS OF METALS AND MICROORGANISMS

BIOHYDROMETALLURGY

Proceedings of the International Symposium held at Jackson Hole, Wyoming August 13 - 18, 1989

Edited by

Joseph Salley, Ron G.L. McCready, Paul L. Wichlacz

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

CANMET SP89-10

TABLE OF CONTENTS

PROCEEDINGS OF THE
NINTH INTERNATIONAL SYMPOSIUM OF BIOHYDROMETALLURGY (1991)
WERE PUBLISHED IN FEMS MICROBIOLOGY REVIEWS, 1993

75[th] Event of the European
Federation of Biotechnology

IX international symposium
BIOHYDROMETALLURGY' 91

edited by
Dr. J. Cardoso Duarte,
LNETI (Portugal)

and
Dr. R.W. Lawrence,
Coastech Research Inc. (Canada)

september 9-13
Tróia . Portugal

BOOK OF PROCEEDINGS

FORBITEC
editions

COMMUNICATIONS

SESSION 1: Microbiology and Genetics.

Chairman — P. NORRIS

1 · 1 D. E. Rawlings, R. A. Dorrington, J. Rohrer and A-Marie Clennel (University of Cape Town, Rondebosch — South Africa)
«A molecular analysis of the replication and mobilization regions of a broad-host-range plasmid isolated from Thiobacillus ferrooxidans»

1 · 2 R. C. Blake II, E. A. Shute, M. M. Greenwood and G. H. Spencer (Meharry Medical College, Nashville — USA)
«Enzymology of respiratory iron oxidation»

1 · 3 P. J. Holden and D. J. M. Stone, (Australian Nuclear Science and Technology Organization, Menai — Australia)
«Amplification of ribulose bisphosphate carboxylase/oxygenase large subunit (RuBisCO LSU) gene fragments from Thiobacillus ferrooxidans and a moderate thermophile using polymerase chain reaction (PCR)»

1 · 4 T. Kusano, K. Sugawara, M. Numata and T. Takeshima, (Akita Pref. Coll. Agric., Akita, Japan) C. Ipoue and T. Shiratori, (Dowa Mining Co. Ltd., Tokyo, Japan)
«Plasmidal transformation of Thiobacillus ferrooxidans»

1 · 5 F. F. Roberto, D. F. Bruhn and T. E. Ward, (Idaho National Engineering Laboratory, USA)
«Phylogenetic and Biochemical characterization of acidophilic bacteria»

1 · 6 M. Seeger and C. A. Jerez, (Fac. Medicina, Universidad de Chile, Santiago — Chile
«Molecular response of Thiobacillus ferrooxidans to phosphate starvation»

SESSION 2: Leaching Microbiology and Mechanisms

Chairman — B. MARCHANT

2·1 P. R. Norris and R. A. Neal, (University of Warwick, Coventry – UK)
«Novel thermophilic mineral oxidizing bacteria»

2·2 J. Barrett, D. K. Ewart M. N. Hughes and R. K. Poole, (King's College London, UK)
«Chemical and biological pathways in the oxidation of arsenopyrite and arsenic (III)»

2·3 D. B. Johnson, M. A. Ghauri and McGiness, (School of Biological Sciences, Univ. of Wales – UK)
«Biogeochemical cycling of iron and sulfur in leaching environments»

2·4 J. T. Pronk, J. P. van Dijken, P. Bos and J. G. Kuenen, (Delft University of Technology, The Netherlands)
«Formic acid metabolism in acidophilic thiobacilli»

2·5 N. N. Lyalikova and N. A. Yurkova, (USSR Academy of Sciences, Moscow – USSR)
«The role of microorganisms in transformation of Vanadium compounds and their removal from industrial wastes»

2·6 H. Mikael Sehlin, K. B. Hallberg and E. B. Lindström, (University of Umeå, Sweden)
«Toxicity of arsenic in the bioleaching process»

2·7 C. Mustin, Ph. de Donato, J. Berthelin, Marion, CNRS (Vandoeuvre-les Nancy, France)
«Relation between the sulphur surficial layer and the electro chemical [redacted] *pyrite* [redacted] *its o*[redacted] *by*

SESSION 3: Mineral Leaching Studies

Chairman — N. LE ROUX

3·1 A. W. Schroeter and W. Sand, (University of Hamburg, Microbiology Germany)
«Estimations on the degradability of ores and on the bacterial leach activity by short time microcalorimetric tests»

3·2 K. A. K. Alibhai, A. W. L. Dudeney and D. Leak, (Imperial College of Science Technology and Medecine, London – UK)
S. Agatzini, (National Technical University, Athens – Greece)
«Bioleaching and bioprecipitation of Nickel and Iron from laterites»

3·3 H. P. Beaumont, P. C. Pereira and J. C. Duarte, P. C. Estrada, (LNETI/ICTM - Portugal)
«Thermophilic vs Mesophilic bioleaching process performance»

3·4 L. Toro, A. Lepidi, F. Vegliò, M. Terreri and B. Paponetti (University of L'Aquila, Italy)
«Manganese bioleaching from pyrolusite: bacterial properties relevant for the process»

3·5 J. A. Muñoz, F. Gonzalez, A. Ballester and M. L. Blazquez, (Univ. Complutense de Madrid, Spain)
«Bioleaching of a Spanish uranium ore»

3·6 C. Krafft and R. O. Hallberg, (University of Stockholm, Sweden)
«Bacterial leaching of two Swedish zinc sulfide ores»

3·7 I. Palencia, M. Iglesias, R. Romero and F. Carranza, (Univ. Sevilla Spain)
«Kinetics improvement of high grade sulphides bioleaching by effects separation»

3·8 K. Runnion and J. Combie, (J. K. Research, Bozeman – USA)
«Organic sulfur remo[redacted] *co*[redacted] *microorganisms from extreme* [redacted]

SESSION 4: Biosorption and Waste Treatment

Chairman — J. BRIERLEY

4 · 1 M. Tsezos. (McMaster University, Ontario — Canada)
«The effect of competing ions on the biosorptive recovery of metals: mechanistic and pilot plant studies»

4 · 2 M. Brunko, W.-D. Deckwer, A. Frischmuth, J. M. Horn, H. Lunsdorf, M. Rohricht, K. N. Timmis and P. Weppen, (Gesellschaft fur Biotechnolog. Forschung mbH. Braunschweig - Germany)
«Microbial retention of mercury from wastestreams in a small scale bioreactor using natural and genetically engineered mer^r-bacteria»

4 · 3 M. Kalin. (Boojum Research Ltd. Ontario — Canada)
«Microbial alkalinity generation for treatment of acid mine drainage»

4 · 4 M. Ghiani, G. Loi, P. Trois and G. Rossi, (University of Cagliari, Italy)
«Microbial purification technique of mineral dressing plant reject waters»

4 · 5 T. Pumpel and F. Schinner, (University of Innsbruck, Austria)
«Native fungal pellets as a biosorbent for heavy metals»

4 · 6 T. Shiratori and H. Sonta, (Dowa Mining Co., Ltd. Japan)
«Application of iron oxidizing bacteria to hydrometallurgical flue dust treatment and H_2S desulfurization»

4 · 7 Special Presentation
M. M. Vrvic (Fac. of Chemistry, Univ. Belgrade-Yugoslavia) J. I. Vucetic (Inst. of Chemistry, Technol. and Metallurgy — Belgrade — Yugoslavia)
«Microbial biogeotechnology in Yugoslavia: present state and future prospects»

SESSION 5: Treatment of Refractory Gold Ores

Chairman — J. WHITLOCK

5 · 1 G. S. Hansford, (University of Cap Town, South Africa)
D. M. Miller, (Genmin Process Research, South Africa)
«Biooxidation of a gold bearing pyrite arsenopyrite concentrate»

5 · 2 G. Pantelis and A. I. M. Ritchie, (Australian Nuclear Science and Technology Organisation, Menai — Australia)
«Rate controls on the oxidation of heaps of pyritic material imposed by upper temperature limits on the bacterially catalysed process»

5 · 3 J. A. Budden and P. A. Spencer, (BacTech Pty Ltd. Cannington — Australia)
«Tolerance to temperature and water quality for bacterial oxidation The benefits of Bactech's moderately termophilic culture»

5 · 4 R. Claassen, (Mintek, Randburg — South Africa)
«Mineralogical controls on the bacterial oxidation of refractory barberton gold ores.»

5 · 5 X. Liu, S. Petersson and A. Sandstrom, (University of Umeå, Sweden)
«Continuous bench-scale bioleaching of the Olympias concentrate»

5 · 6 H. Maturana, U. Lagos, V. Flores, M. Gacte, L. Cornejo and J. V. Wiertz, (University La Serena, Chile)
«Integrated biological process for gold recovery from a complex chilean ore»

5 · 7 L. Castro and M. C. Rossi, (Centro Investigación Minera y Metalurgica, Santiago — Chile)
«Bio oxidation in columns of a chilean refractory gold ore»

5 · 8 W. Hoffmann, N. Katsikaros and G. Davis (CRA Advanced Technical Development, Newcastle, Australia)
«Bioleaching reactor scale up for refractory gold»

SESSION 6: Pilot Plants and Case Studies

Chairman — R. LAWRENCE

6·1 S. Bustos, S. Castro, R. Montealegre, (Sociedad Minera Pudahuel Santiago — Chile)
«The SMP bacterial TL-Leaching process at LO Aguirre»

6·2 O. Garcia Júnior, (UNESP, Inst. de Química, São Paulo — Brazil)
«Bacterial leaching of uranium ore from Figueira-PR, Brazil, at laboratory and pilot scale»

6·3 J. T. Chapman, P. B. Marchant and R. W. Lawrence, (Lawrence, Marchant Ltd., North Vancouver — Canada)
R. Knopp, (Dickenson Mines Ltd, Ontario — Canada)
«Mobile bioleach pilot plant operation — continuous bio-oxidation of a refractory gold bearing high arsenic flotation concentrate»

6·4 J. Cerdá, S. González, J. M. Rios and T. Quintana, (ENUSA — SPAIN)
«Uranium concentrates bioproduction in Spain (A study case)»

6·5 S. N. Groudev, (Research Training Centre of Mineral Biotechnology — Bulgaria)
V. I. Groudeva, (Univ. Sofia, Fac. of Biology, — Bulgaria)
«Microbial communities in four industrial copper dump leaching operations in Bulgaria)

6·6 W. Sand, K. Rohde and B. Sobotke, (University of Hamburg, Microbiology, Germany)
«Development and monitoring of lithotrophs in the microbi al in situ stope leaching at Ilba mine (Romania)»

6·7 V. Oros, M. Peterfi, M. Bivolaru, S. Kovacs, M. Jelea and I. Hudrea, (ICITPMN, Romania)
«Production of cooper and zinc by microbial in situ stope leaching at Ilba mine (Romania)»

BIOHYDROMETALLURGICAL TECHNOLOGIES

VOLUME I

Bioleaching Processes

Proceedings of
an INTERNATIONAL BIOHYDROMETALLURGY SYMPOSIUM
held in Jackson Hole, Wyoming, USA, August 22-25, 1993

EDITED BY

A.E. Torma
J.E. Wey
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BIOHYDROMETALLURGICAL TECHNOLOGIES

VOLUME I

Bioleaching Processes

TABLE OF CONTENTS

BIOHYDROMETALLURGICAL TECHNOLOGIES

VOLUME II

Fossil Energy
Materials
Bioremediation,
Microbial Physiology

Proceedings of
an INTERNATIONAL BIOHYDROMETALLURGY SYMPOSIUM
held in Jackson Hole, Wyoming, USA, August 22-25, 1993

EDITED BY

A.E. Torma
M.L. Apel
C.L. Brierley

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BIOHYDROMETALLURGICAL TECHNOLOGIES

VOLUME II

Fossil Energy Materials, Bioremediation, and Microbial Physiology

TABLE OF CONTENTS

ADDITIONAL REFERENCE MATERIAL

Following are tables of contents of other conference proceedings and books containing useful material on biotechnology in mining.

PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM ON
IMPURITY CONTROL AND DISPOSAL IN
HYDROMETALLURGICAL PROCESSES,
TORONTO, ONTARIO, CANADA, AUGUST 21-24, 1994

Impurity Control and Disposal in Hydrometallurgical Processes

24th Annual Hydrometallurgical Meeting

Editors:
B. Harris
Mining Industry Technology Council of Canada (MITEC)
Ottawa, Ontario, Canada

E. Krause
Inco Limited
Mississauga, Ontario, Canada

Symposium sponsored by the Hydrometallurgy Section of
The Metallurgical Society of CIM

33rd ANNUAL CONFERENCE OF METALLURGISTS OF CIM
33e CONFÉRENCE ANNUELLE DES MÉTALLURGISTES DE L'ICM

BIOLEACHING — A TECHNOLOGY FOR TODAY

Microbial Mineral Recovery

Henry L. Ehrlich
Department of Biology
Rensselaer Polytechnic Institute
Troy, New York

Corale L. Brierley
VistaTech Partnership, Ltd.
Salt Lake City, Utah

McGraw-Hill Publishing Company
New York St. Louis San Francisco Auckland Bogotá
Caracas Hamburg Lisbon London Madrid Mexico
Milan Montreal New Delhi Oklahoma City
Paris San Juan São Paulo Singapore
Sydney Tokyo Toronto

Contents

Biotechnology For the Mining, Metal-Refining, and Fossil Fuel Processing Industries

Proceedings of a Workshop
Held at Rensselaer Polytechnic Institute in Troy, New York
May 28-30, 1985
Sponsored by the
National Science Foundation, General Electric Company,
Rensselaer Polytechnic Institute, and EG&G Idaho, Inc.

Co-Editors
Henry L. Ehrlich
Biology Department, Rensselaer Polytechnic Institute
and
David S. Holmes
Corporate Research and Development, General Electric Company

an Interscience® Publication
published by John Wiley & Sons

Contents

CONTENTS

CONTENTS

MICROBIOLOGICAL EFFECTS ON METALLURGICAL PROCESSES

Proceedings of The Metallurgical Society/Society of Mining Engineers Joint Committee on Hydrometallurgy/Processing and The Metallurgical Society-Physical Chemistry Committee, held at the AIME Annual Meeting held at New York, New York, February 24-28, 1985.

Edited by

J.A. Clum
Thomas J. Watson School of Engineering
Binghamton, New York 13901

L.A. Haas
United States Bureau of Mines
Minneapolis, Minnesota

A Publication of The Metallurgical Society, Inc.

Table of Contents

DISCUSSION

FRONTIER TECHNOLOGY IN MINERAL PROCESSING

Co-Editors

John F. Spisak
Vice President, Operations
Anschutz Mining Corporation
Denver, Colorado

Gerald V. Jergensen, II
Humphreys Mineral
Industries Incorporated
Denver, Colorado

This volume was originated by the Mineral Processing Division of the Society of Mining Engineers of AIME to serve as a source of ideas for frontier technology in the metals and minerals industries.

Society of Mining Engineers
of the
American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.
New York, New York • 1985

TABLE OF CONTENTS